STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

Central District

LAKE ALMANOR LIMNOLOGIC INVESTIGATION

A Study by the Department of Water Resources and the Department of Fish and Game

APRIL 1974

FOREWORD

The California Departments of Water Resources and Fish and Game cooperated in conducting a limnology study of Lake Almanor. This lake, located in the Feather River Basin in Plumas County, is operated by Pacific Gas and Electric Company for hydroelectric power generation. It is one of the largest in the State, with a surface area of over 25,000 acres. Recreational activities and fishing are of considerable importance. However, the fishery in recent years has been declining.

The watershed is being developed with second homes, which are increasing the amount of wastes entering the lake and could cause future problems. There is a need to better plan the development of the basin and to improve the fishery by stocking game fish best adapted to the lake and by providing better forage fish. Limnology relationships indicate that further increases in nutrient entry could lead to a shift from a salmonid assemblage to less desirable species.

Robin R. Reynolds

Robin R. Reynolds
District Engineer
Central District
Department of Water Resources

April 3, 1974

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State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
Central District

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CHAPTER I

SUMMARY AND RECOMMENDATIONS

1. Lake Almanor is a 60-year old reservoir operated by the Pacific Gas and Electric Company in conjunction with its other North Fork Feather River hydroelectric power generating facilities.

2. Current base line limnologic conditions of Lake Almanor are generally good and are summarized as follows:

   a. Concentrations of nitrogen and phosphorus during the 1973 spring overturn were low and such concentrations should not contribute to the overproduction of algae in the broad open waters of the lake.

   b. Dissolved Oxygen (DO) may not be a problem to fish-life in the lake since water strata were present with DO concentrations of 5 milligrams per liter, associated with temperatures of 59° F., or less, during the entire warm seasons of 1969 and 1973.

   c. Standing crops of phytoplankton which existed in the lake on several occasions during 1973 are comparable to those of other lakes where total fish production is satisfactory.

   d. Zooplankton levels in the lake should be adequate to support a fairly substantial fish population.

3. An evaluation of the current limnologic conditions indicates that the overall biologic productivity is at a moderate level and this productivity results from a well-balanced biologic community.

4. In the evaluation of environmental effects of proposed developments, careful consideration should be given to the contribution of additional nutrients to the lake. These nutrients could lead to undesirable algal conditions and could also lead to a shift in the fishery from a salmonid assemblage to less desirable species.

5. Fishery improvements can best be achieved by the following management practices:

a. Stocking game fish best adapted to Lake Almanor.

b. Restructuring the size composition of nongame fish populations.

c. Establishment of a satisfactory forage fish population.

6. Unless a system could be designed which would aerate the hypolimnion without causing reservoir mixing, the aeration of Lake Almanor would result in undesirably high temperatures in the aerated portions.

7. Management of the lake should include a program of limnologic monitoring to detect changes and indicate the need for changes in management of the basin and/or the lake.

8. The in situ worth of Lake Almanor is great and should be protected and maintained by establishment of regulations for basin development and by the adoption of good management practices for land use in the basin. Information in this report should be useful in determining the need for a comprehensive study of resources and land uses in the watershed.

CHAPTER II

INTRODUCTION

Lake Almanor is very attractive, with Mt. Lassen and other background features providing many magnificent views across the vast water surface. These views are further enhanced by the beautiful stands of fir, pine, and cedar which grow on much of the shore and surrounding hills. These aesthetic qualities, combined with the size of the lake, contribute to its desirability for recreational uses, such as fishing, boating, and water contact sports. These same qualities make the lands near its shores attractive to those seeking sites for recreational homes.

The importance of Lake Almanor as a body of water is given emphasis by a comparison of its storage capacity and surface area to the same features of other reservoirs inside California. When compared in this manner, it ranks seventh in order of storage capacity and second in order of surface area. The following tabulation provides comparisons of sizes of certain well known California reservoirs.

Reservoir	Capacity (Acre-Feet)	Surface Area (Acres)
Shasta Lake	4,500,000	29,500
Lake Oroville	3,484,000	15,500
Don Pedro Reservoir	2,030,000	12,960
Lake Berryessa	1,600,000	20,700
Lake Almanor	1,036,000	26,243
Folsom Lake	1,010,000	11,450

Purpose and Scope of Investigation

The basis for this report was a cooperative investigation made by the California Departments of Water Resources and Fish and Game. These two

departments recognized a common interest in this major body of water and agreed to undertake the joint study. The field work for the study was conducted during the period October 1972 through October 1973 (from one fall overturn of the lake through the next).

The Department of Water Resources' portion of the investigation was funded by the Water Quality Investigations Program. The Department of Fish and Game's work was performed as part of Dingell-Johnson Project, California F-26-R, "Lake Almanor Fisheries Investigation", supported by federal aid to fish restoration funds. The Lake Almanor Fisheries Investigation commenced on July 1, 1969.

The objectives of the joint investigation were:

1. To obtain current base line limnologic data for Lake Almanor.

2. To evaluate the overall biologic productivity of Lake Almanor.

The three major purposes for conducting the study were:

1. Provide information useful in evaluating the environmental effects of proposed developments within the drainage basin.

2. Provide information for use in the management of the Lake Almanor fishery.

3. Provide a basis for determining the need for a comprehensive study of resources and land uses of the drainage basin.

Data Collection

Field activities were conducted by crews composed of personnel from both agencies.

These activities consisted of the following:

1. Collection of field data from the lake on twelve occasions. (Laboratory samples were also collected on most of these instances.)

2. Collection of field data and laboratory samples from the major streams tributary to the lake on one occasion during spring runoff.

Laboratory analyses, both mineral and biologic, were funded by the Department of Water Resources. These analyses were performed at the Department of Water Resources' Bryte Laboratory, with the exception of the benthic examinations which were performed by a contract laboratory.

Watershed Characteristics

General

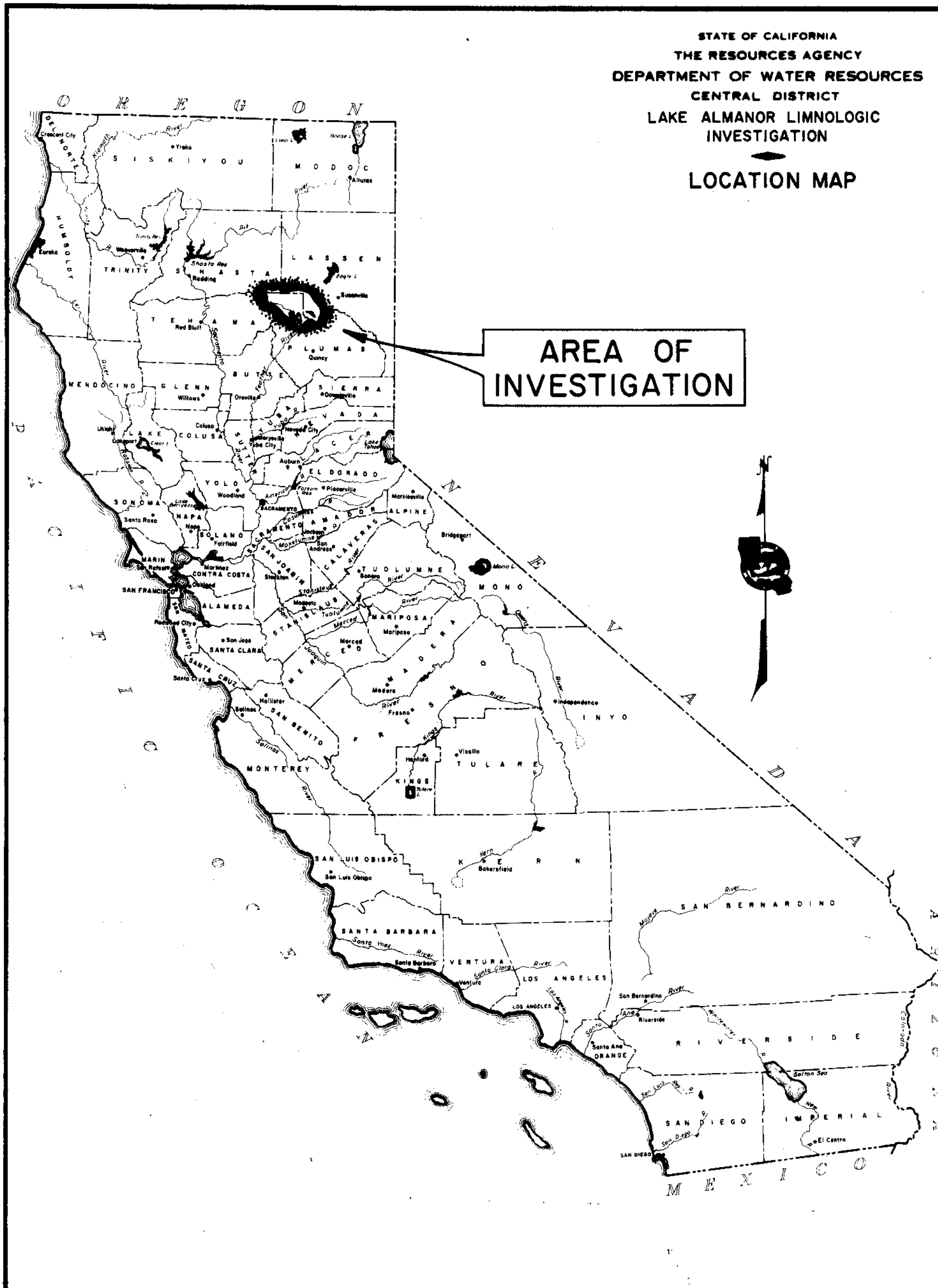
Lake Almanor Watershed, the location of which is shown on Plate 1, is the headwaters of North Fork Feather River, and is located in Plumas, Lassen, and Shasta Counties. The Feather River is one of the principal tributaries to the Sacramento River. Some of the streams in the basin, in addition to North Fork Feather River, are Baily, Benner, Last Chance, Mud, and Rock Creeks, and Hamilton Branch. The drainage area of Lake Almanor is 493 square miles.

Chester and Westwood are the two major communities in the watershed. The permanent population of the watershed in 1970 was about 4,100 people, the majority of whom lived in the two communities or along the shores of Lake Almanor.

The major highways in the watershed are state sign Route 36 which traverses the watershed primarily east to west, Route 89 which runs along the southwesterly shore of Lake Almanor, and Route 147 which runs along the easterly shore. Branch lines of both the Western Pacific and Southern Pacific Railroads are in the watershed.

Much of the watershed is mountainous, with elevations ranging from around 4,500 feet at Lake Almanor to over 9,000 feet on the slopes of Mt. Lassen. With the exception of Mt. Lassen, outstanding peaks in the watershed range from 6,000 to over 8,000 feet in elevation. Main ridge orientations are normally from a northwest to southeast direction. Most of the watershed is in coniferous forest.

PLATE I


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
LAKE ALMANOR LIMNOLOGIC INVESTIGATION
LOCATION MAP
AREA OF INVESTIGATION
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN

Geology

The drainage basin tributary to Lake Almanor spans the boundary between the Cascade Range and Sierra Nevada geomorphic provinces.

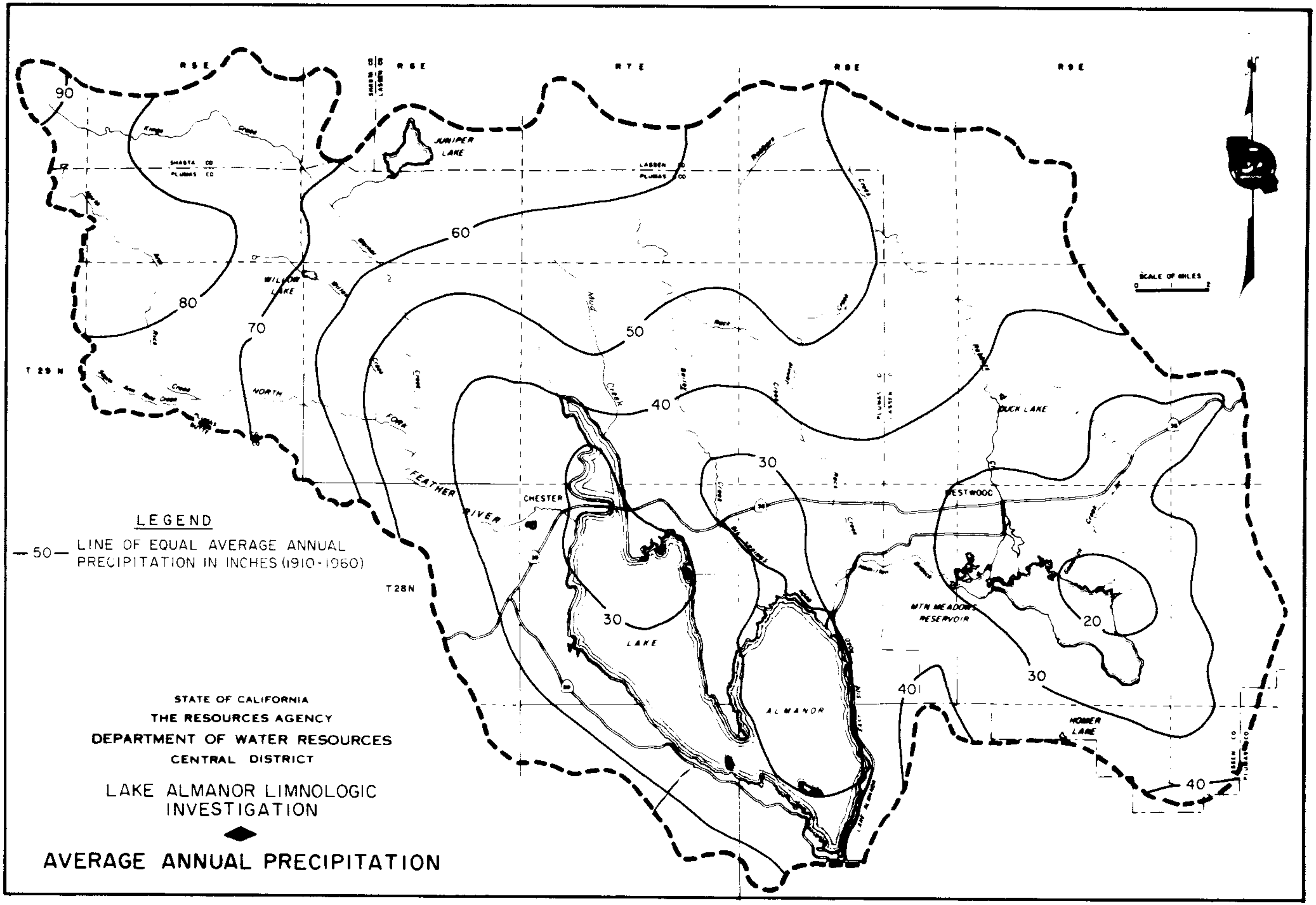
Lava flows and other fine-textured volcanic rocks characteristic of the Cascade Range underlie the northwestern two-thirds of the drainage basin and enclose Lake Almanor Valley on three sides. Basalt flows of Pliocene age, older than 2 million years, are the most abundant of the volcanic rocks, but andesite flows of Pliocene age and basalt flows and pyroclastics of Quaternary age underlie a significant part of the drainage basin.

A variety of metamorphic rock units underlie the southeastern third of the drainage basin. These rocks outcrop along the east and south margins of Lake Almanor, and enclose on three sides the Mountain Meadows Reservoir valley which lies to the east of Lake Almanor. These older rocks which are typical of the Sierra Nevada include metavolcanic rocks of Paleozoic and Mesozoic age, and lesser amounts of other metamorphic rocks, such as hornfels, slate, limestone, graywacke and quartzite, also of Mesozoic age, which were intruded by granitic rocks.

The floors of the valleys adjacent to Lake Almanor and Mountain Meadows Reservoir are underlain by Quaternary and older alluvium and lake sediments.

Climate

The climate of the Lake Almanor Watershed is similar to that of other areas of the Sierras. Precipitation varies from 20 to 30 inches in the vicinity of Lake Almanor, Chester, and Westwood to 90 inches on the slopes of Mt. Lassen, as shown on Plate 2. Average precipitation throughout the watershed is about 46 inches. Most precipitation occurs in the winter, with much of the moisture falling in the form of snow.



LEGEND

— 50 — LINE OF EQUAL AVERAGE ANNUAL PRECIPITATION IN INCHES (1910-1960)

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

LAKE ALMANOR LIMNOLOGIC INVESTIGATION

AVERAGE ANNUAL PRECIPITATION

PLATE 2

Air temperatures in the watershed are moderately severe during the winter, often falling below freezing between November and March. The summer months generally are warm and pleasant, though the summer nights are usually cool. For comparison, the monthly temperatures for the spring and summer of 1973 and the departure of these temperatures from the normal mean monthly air temperatures are shown on Table 1. Differences between the maximum and minimum daily air temperatures are frequently great. Frost can occur during any month of the year.

Table 1
1973 AIR TEMPERATURES NEAR LAKE ALMANOR

	Canyon Dam		Chester*
	Monthly Mean	Departure of Mean From Normal	Monthly Mean
April	44.5	-0.3	44.4
May	56.2	+4.3	55.4
June	61.8	+2.9	60.4
July	67.9	+1.5	66.3
August	65.2	+0.5	--
September	58.3	-0.9	57.8

Temperatures are in degrees Fahrenheit.

Source: Climatological Data, California, Volume 77, by U. S. Department of Commerce.

Development

The major activities of man in the watershed are logging, cattle production, hydro-electric power generation, and recreation. Logging has long been a major activity in the area as has cattle production. Hydro-electric power generation also has existed for a number of years through operation of the North Fork Feather River facilities by the Pacific Gas and Electric Company.

*Departures of mean from normal not available for the Chester Station.

Recreation has long been a major activity in the area and is probably becoming more important each year. The significance of the recreation and logging activities is indicated by the summer population of the area which is more than double the permanent population.

Even with all of man's activities, only a small part of the watershed is developed. If present population were spread evenly throughout the watershed, there would only be about eight people per square mile. It is primarily this lack of development which maintains the lakes in the area in their present attractive state, while those in other more developed areas frequently show signs of deterioration.

The major cause of water quality deterioration from land development is the disposal of wastes. The only central sewage collection, treatment, and disposal systems in the watershed are located in the communities of Chester and Westwood. Chester uses Imhoff tanks and oxidation ponds for treatment, and discharges treated effluent directly into Lake Almanor. Westwood uses sewage ponds for treatment, with no surface discharge from the ponds. Exclusive of the Chester and Westwood systems, individual septic tanks and leaching fields are the primary means for waste disposal.

CHAPTER III

LAKE ALMANOR HYDROLOGY

Lake Almanor Dam was constructed in 1913 and subsequently raised in 1917 and again in 1927, and further modified in 1962. The maximum storage capacity at the spillway lip is 1,308,000 acre-feet, with a gage reading of 4,500.0 feet (equal to a surface elevation of 4,510.2 feet above sea level). For normal operation, a maximum storage of 1,036,000 acre-feet at a gage reading of 4,490.0 feet (surface elevation 4,500.2 feet) is maintained. The lake has never spilled since the construction of a higher dam and spillway in 1927.

Stream maintenance flows for North Fork Feather River are released from the lake through an outlet tower at the dam. Presently, releases can be made through gates at elevations of 4,477.2 feet, or 4,432.2 feet.

Diversions from the lake are made at the Prattville Tower, through Butt Creek Tunnel, for use at Butt Creek Powerhouse. The intake gate of the tower is at elevation 4,420.2 feet; however, a dredged channel with invert elevation of 4,432.2 feet conveys water to this gate. The 9-foot gate can only be operated full open of or full closed.

The Pacific Gas and Electric Company operates Lake Almanor in conjunction with its other North Fork Feather River hydroelectric power generating facilities. Releases from Lake Almanor satisfy operating requirements of Butt Creek Powerhouse and supplemental requirements of other downstream powerhouses. Plate 3 is a schematic diagram prepared by the U. S. Geological Survey, showing the diversions and storage in the North Fork Feather River Basin. Storage in and releases from Lake Almanor, as well as flows into Lake Almanor from Mountain Meadows Reservoir, are measured at three gaging stations, as listed on Table 2.

Runoff from the Lake Almanor Watershed since 1913 has averaged over 650,000 acre-feet per year, which is equal to 25 inches of water over the entire

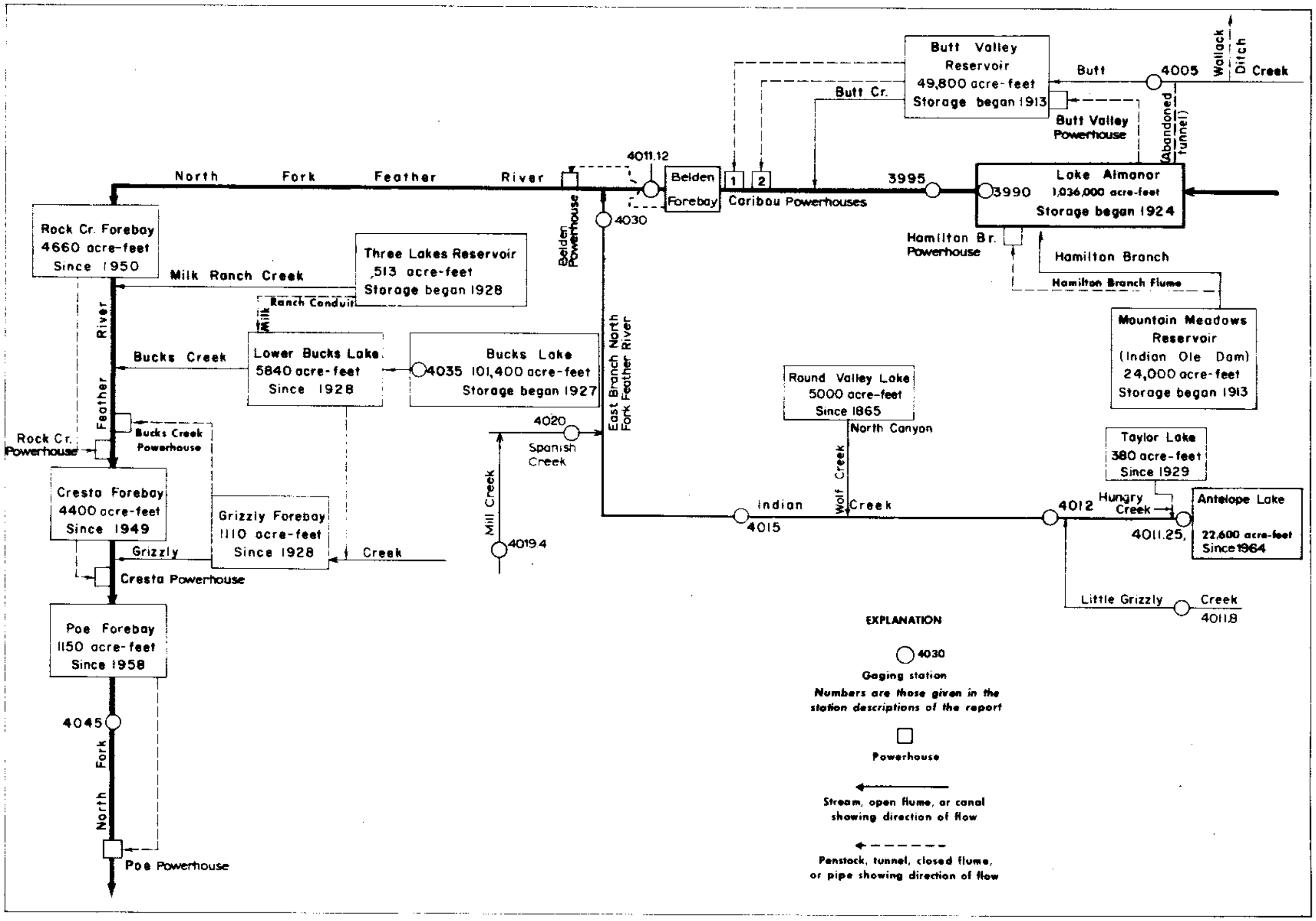


FIGURE 12.--Schematic diagram showing diversions and storage in North Fork Feather River basin.

(Reproduced with permission of U. S. Geological Survey)

watershed area. This can be compared to an average annual precipitation on the watershed of about 46 inches.

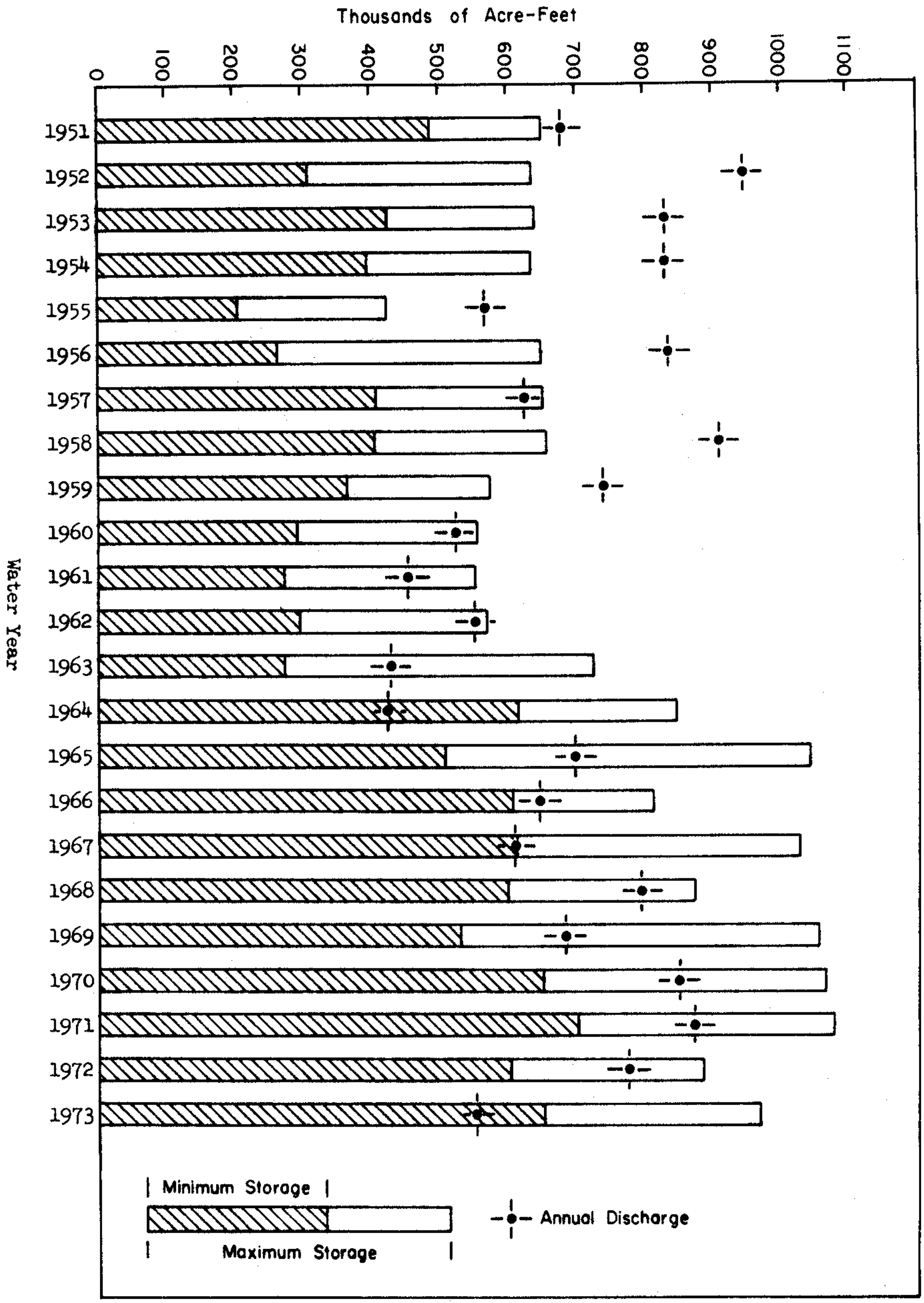
Table 2
GAGING STATIONS
Lake Almanor

Number DWR / USGS	Description	Location	Source of Record	Period of Record
A-5-3600 / 11-3995.00	North Fork Feather River near Prattville	27N/08E-28L	PG&E	1905 - Present
A-5-3630 / 11-3990.00	Lake Almanor at Prattville	27N/07E-11G	PG&E	1913 - Present
A-5-3675 / 11-3984.00	Mountain Meadows Reservoir near Westwood	28N/08E-13J	PG&E	1931 - Present

Maximum and minimum annual storage and discharge for Lake Almanor for the water years 1950-51 through 1972-73 are shown on Plate 4. The plate indicates that from 1950 to 1962 only 650,000 acre-feet of the total storage capacity was used. A modification of the dam permitted use of additional storage after 1962.

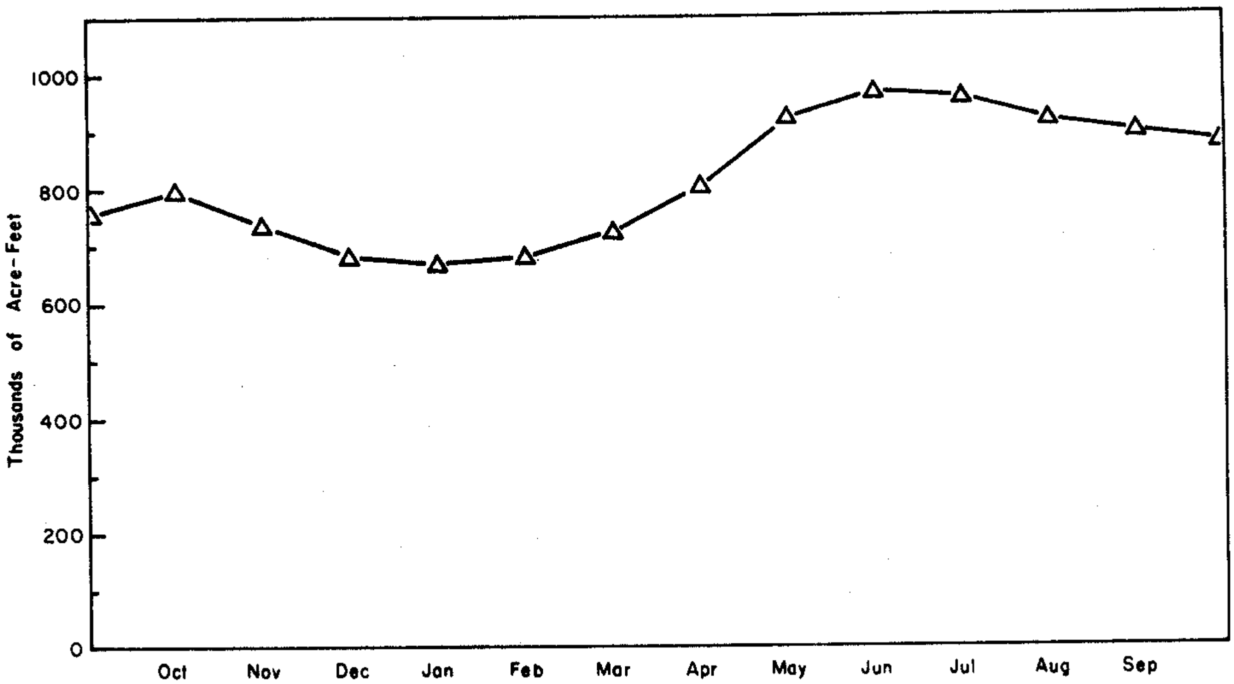
For the period 1951-62, the maximum annual storage averaged about 599,000 acre-feet, but for the period 1964-73, after the usable storage capacity was increased, the maximum annual storage averaged about 977,000 acre-feet. The average minimum annual storage, as indicated on Plate 4, also changed during the two periods from 343,000 acre-feet in 1951-62 to 606,000 acre-feet in 1964-73. By this change in operation, the average minimum annual water surface area increased by about 4,500 acres.

Plate 5 shows the monthly operation of Lake Almanor during the period of the study. Lake discharge was about 550,000 acre-feet in the 1972-73 water year, however, the reservoir storage increased by over 134,000 acre-feet during the period. Total inflow to the lake was about 104 percent of normal. Maximum and minimum storages for 1972-73 were about equal to the 1964-73 averages.

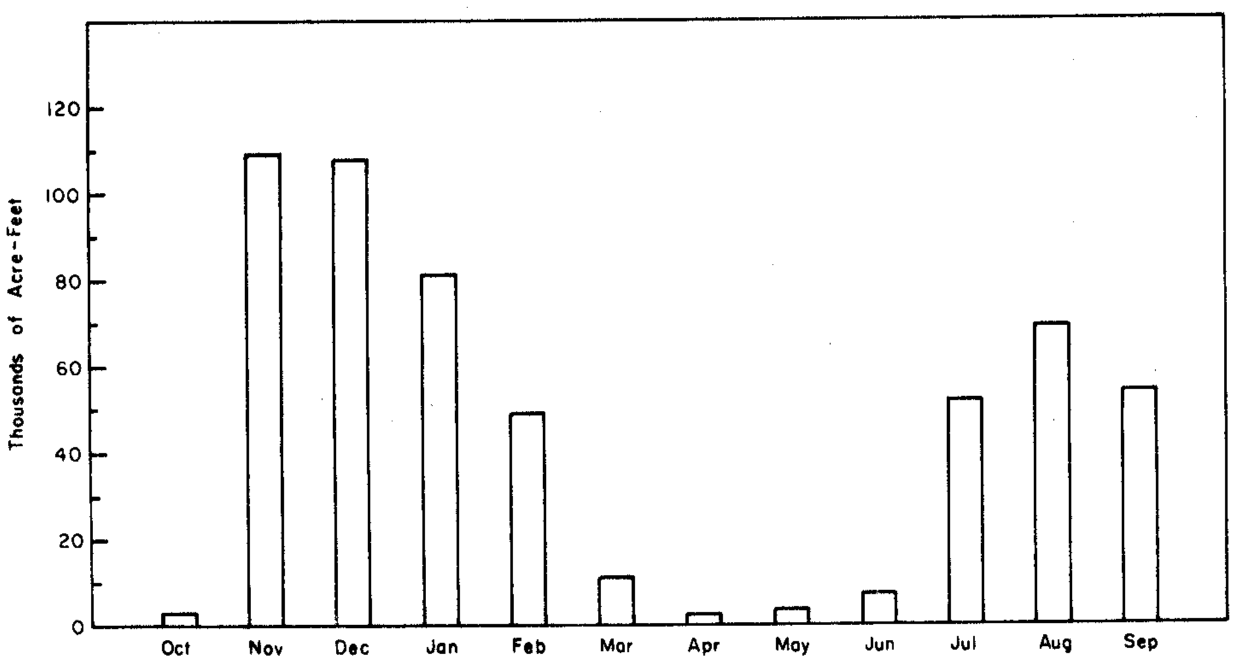


LAKE ALMANOR HYDROLOGY, 1951-73

LAKE ALMANOR HYDROLOGY, 1972-73



End of Month Storage



Monthly Discharge

CHAPTER IV

FIELD AND LABORATORY METHODS

During the course of the investigation, a wide variety of parameters were determined or observed. This required the use of many different techniques and various types of equipment. In most instances the techniques and equipment were fairly standard or at least commonly used by many other investigators. In a few instances, relatively new methods were tested.

Field Determinations

Certain water quality parameters are of such a nature that they require in situ determinations. Other parameters undergo change soon after samples are collected and require determinations in the field.

In Situ

Transparency determinations were made using a secchi disk of 20 centimeters diameter with alternate black and white quadrants suspended on a metallic cloth tape. The disappearance and reappearance depths were noted and the average of the two depths was recorded.

Light transmittance was measured by lowering a photocell with waterproof housing to various depths and reading an ammeter which was connected by conductor cable to the cell. The instrument used was a Kahl Submarine Photometer. The values obtained in the above manner were later converted to a percentage of the reading made with the cell in air held horizontally and above all reflecting objects in and around the boat.

Temperature was measured by use of a depth thermistor which could be lowered to specific depths. The two instruments used were a Yellowsprings Tele-thermometer and an Applied Research thermistor.

Collected Samples

Temperature was also determined on collected samples by use of an A.S.T.M. mercury thermometer with 0.2 degrees F. divisions which was mounted inside a lucite-walled Kemmerer sampler. This helped verify the validity of the thermistor readings and also gave assurance that the sample had been collected at the intended depth.

The pH determinations were made using a Hellige color comparator. The indicators used were bromthymol blue (6.0-7.6), phenol red (6.8-8.4) and thymol purple (7.6-9.2).

Specific conductance, or electrical conductivity (EC), was measured with a Beckman Solubridge with 0.2K cell and was reported as micromhos (umhos) per centimeter at 25 degrees centigrade.

Dissolved oxygen (D.O.) analyses were made with a field kit, using the Alsterberg (azide) modification of the Winkler method. Dry reagents in Hach powder pillows were used, followed by titration with a standard thiosulfate solution dispensed from an automatic leveling burette.

Laboratory Samples

Many of the parameters studied in the investigation involved analysis requiring specialized techniques or equipment not suitable for use in the field. Samples for these analyses were taken to a suitable laboratory.

Phytoplankton

All algae samples were collected by use of a Kemmerer sampler. Samples for phytoplankton were placed in a two ounce bottle containing one milliliter of Lugol's solution. As discussed later, chlorophyll fluorescence readings were used to determine which of the phytoplankton samples would be sent to the laboratory for identification and enumeration.

At the laboratory aliquots from those samples selected for further analysis were placed in special settling chambers, and the algae allowed to

settle for several hours. The settled samples were then placed on the stage of an inverted microscope and the organisms found in several microscope fields identified to genus and tabulated. Several representatives of each organism were measured by use of a micrometer eyepiece to obtain their approximate external dimensions. Reference to a chart of standard volumes for various geometrical shapes (cylinders, spheres, etc.) was used to provide estimates of organism volume.

Phytoplankton results were reported in both numbers of organisms per milliliter (derived from data on the number of microscope fields counted, the total area of the microscope slide, and the volume of the settling chamber) and volume of the organisms in cubic standard units (CSU). The volumetric concentration of the phytoplankton was obtained by multiplying the average volume per cell by the number of cells per milliliter and reported as CSU per milliliter (CSU/ml). Multiplication by 8,000 will convert CSU/ml to cubic microns per milliliter (μ^3/ml). One million cubic microns/ml is approximately equal to one milligram of suspended materials per liter (mg/l), assuming that algal cells have about the same density as water.

Zooplankton

Zooplankton (the small, weakly swimming animals) were sampled by means of a 0.9 foot diameter plankton sampler with a #20 silk bolting cloth net. The net was lowered to within about 3 feet of the lake bottom and then pulled to the surface. Any zooplankters clinging to the inside of the net were washed to the bottom cup by pouring water on the net from the outside. The contents of the cup were then quantitatively transferred to a bottle containing a few drops of rose bengal. After a few minutes enough formalin was added to the sample bottle to make a 5 percent solution.

At the laboratory the zooplankters were identified to major taxonomic group only (copepods, cladocerans, etc.) at 50 or 100 magnifications using an inverted microscope. In addition, aliquots of each sample were filtered through

preweighed Whatman GF/C glass fiber filter. The filters were then dried at 103°C for one hour and reweighed. Finally the dried filters were ignited in a muffle furnace (560°C for 15 minutes), cooled and weighed again. The results were reported as organisms per milliliter, as well as mg/l suspended and volatile solids.

Benthic

Qualitative samples of the bottom organisms (benthos) were obtained by a standard Petersen dredge, with only one sample taken at each station. Most of the silt and detritus were washed through a #30 mesh screen, and the material retained on the screen was placed in a plastic bag containing a 5 percent solution of formalin. In the laboratory the organisms were identified by the use of a compound microscope and selected identification keys to the aquatic organisms of California.

Chlorophyll

Estimates of phytoplankton biomass are obtained by various procedures which include counting, weighing, and chlorophyll extraction. All of the procedures can be useful but in general are time-consuming and expensive. To avoid the expense of counting the algae contained in large numbers of Lake Almanor samples, a screening procedure was used to determine which samples would be submitted for further analysis.

The screening technique selected was in vivo flurometry, a test which is based on the fluorescence of the chlorophyll pigment contained in the algal cells. Water samples were collected in the field, iced, returned to the laboratory within 24 hours of the sampling time. Samples were then warmed to about 70° F. and fluorescence readings obtained. The instrument used was a Model III Turner flurometer which had been adopted for the determination of chlorophyll fluorescence by the use of appropriate filters (Corning CS 5-60

primary and a Corning CS 2-60 secondary), correct light source, and a red-photomultiplier. To avoid conversion of readings made using different light control slots, only the 10X slot was used. Where necessary, samples were diluted with distilled water so that readings would always be on-scale. No attempt was made to achieve an exact temperature in all samples being examined, but they were generally in the range of 20-23°C.

When used as a screening technique, as in the Lake Almanor study, *in vivo* chlorophyll has merit, but care must be taken when trying to extrapolate from in vivo reading to algal biomass. There are two major problems involved in the technique: 1) failure to differentiate between viable chlorophyll and phaeophyton (the inactive chlorophyll found in the organic detritus of dead algae and zooplankton fecal material); and 2) the variability in amounts and types of chlorophyll within algal cells caused by different growth stages and algal species.

Minerals

Samples for chemical analysis were collected with a Kemmerer sampler and placed in plastic bottles. The samples for nutrient analysis were iced and delivered to the Department of Water Resources' Bryte Laboratory within 24 hours of collection time.

Other water samples were also taken to the Department's laboratory for chemical analysis. Constituents analyzed included the Department's "standard mineral" (calcium, magnesium, hardness, sodium, potassium, alkalinity, carbonate, bicarbonate, sulfate, chloride, boron, total dissolved solids, and electrical conductivity), nutrients (nitrogen series and phosphorus) and on one occasion, selected heavy metals. All analytical procedures were in accordance with methods outlined in the 13th edition of Standard Methods (American Public Health Association, 1971).

Productivity Estimates

It is important to know how much algae is present at a specific time but it may also be necessary to know how much organic material is being produced per unit time. There are two basic methods which can be used to estimate primary productivity, both of which were tried at Lake Almanor. The two estimates are based on cellular reactions, which can be summarized by the following general equation for photosynthesis.

$$CO_2 + H_2O \xrightarrow[\text{nutrients}]{\text{light}} CH_2O + O_2$$

The first method was tried on June 26, 1973, and is based on the evolution of oxygen by plant cultures actively growing in the light. Samples from various depths at two Lake Almanor stations were collected and aliquots put into BOD bottles. The samples were then suspended at the depth from which they were originally collected by hanging them from an anchored styrofoam float. Some of the bottles were covered with foil to exclude light so that an estimate of the oxygen consumption by respiratory processes could be obtained. The bottles were left in the lake for about 6 hours, retrieved, and immediately fixed for oxygen analysis by the azide modification of the Winkler method, and then titrated. The results during this sampling period indicated that photosynthetic production at the depths tested was too low to be estimated by light-and-dark bottle oxygen evolution techniques since there were no significant changes in oxygen concentration in any bottle during the test.

The productivity experiment was repeated on July 19, 1973, using the more sensitive radioactive carbon technique. The experimental procedure is quite similar to that of the oxygen evolution test except that a small amount, 3 microcuries in this case, of radioactive ^{14}C (in the form of $Na^{14}HCO_3$) was added to each of the bottles. After an in situ incubation

period of 2 hours at the various depths, the bottles were collected, returned to the laboratory and each sample filtered through a 0.45 micron membrane filter.

The filters were then sent to the Clear Lake Algal Research Unit for counting with a Geiger-Mueller counter. Strickland (1960) and Vollenweider (1969) provide complete descriptions of the radioactive test procedure along with some of its limitations.

CHAPTER V

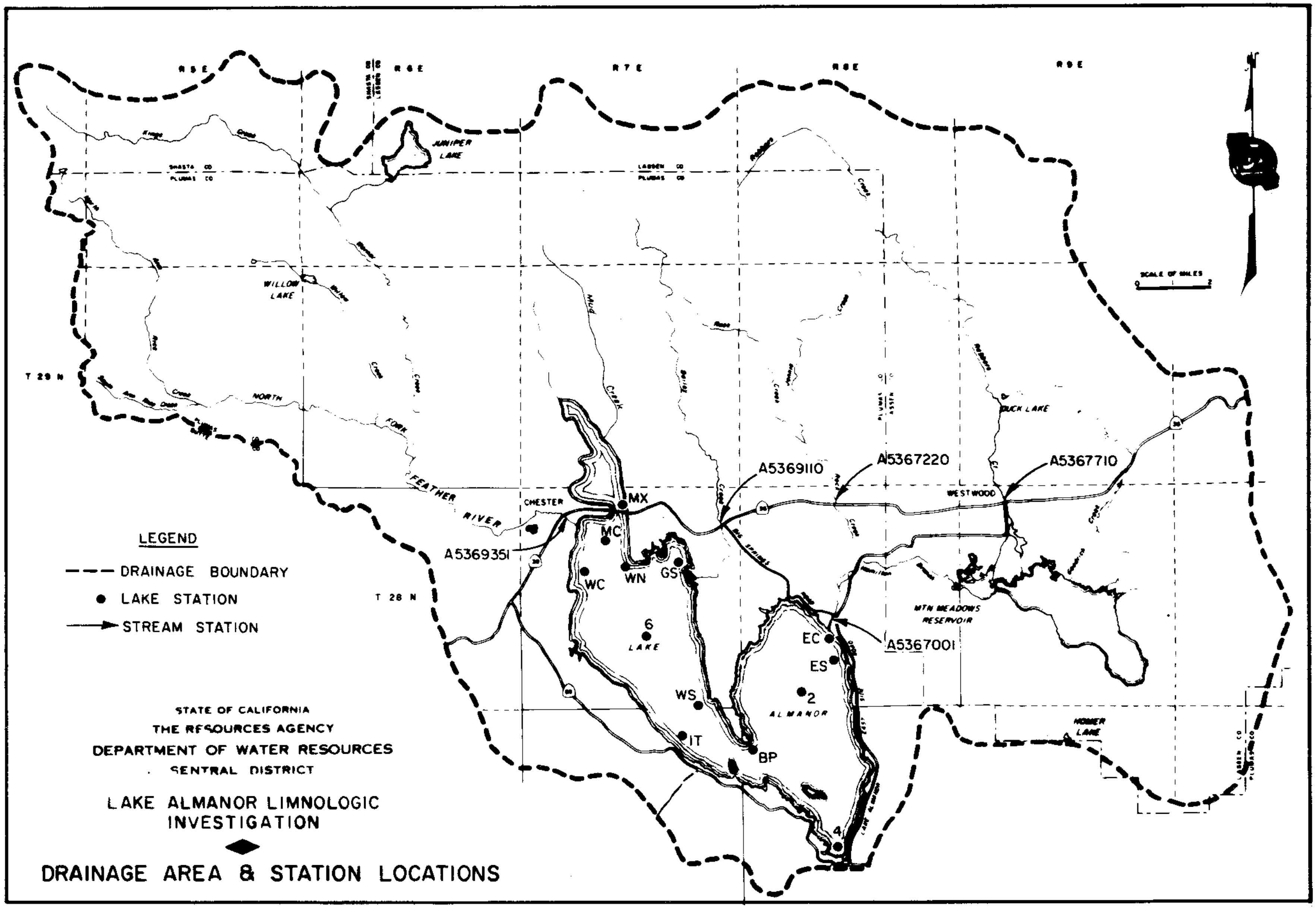
PHYSICAL AND CHEMICAL CHARACTERISTICS

In order to determine the current limnologic conditions of Lake Almanor, field data and samples were collected periodically from a total of 13 sampling stations. A listing of these stations with their identifying numbers or letters appear in Table 3. The location of the stations are shown on Plate 6 and are identified by the last portion of the investigation station designation.

The frequency of visits varied considerably for the different stations, with some being sampled once and others 9 times or more. The major effort was directed to the two stations near the center of each of the two large arms and to the deepest station near the dam. It was felt that data from these stations would be representative of large portions of the lake. The number of analyses from each station is shown in Table 3.

Table 3
LAKE ALMANOR SAMPLING STATIONS

Investigation Station Designation	Department of Water Resources Number	Station Name	Number of Analyses	
			Mineral	Phytoplankton
LA-2	A5L01431065	East Arm, Center	9	28
LA-EC	A5L01551050	East Arm Cove		1
LA-ES	A5L01511048	East Arm, Easterly Shore		2
LA-4	A5L01071051	Near Dam	7	7
LA-BP	A5L01311079	Near Bunnel Point	1	3
LA-IT	A5L01321098	West Arm Nr. Intake Tower	2	
LA-WS	A5L01411092	West Arm, South		1
LA-6	A5L01551111	West Arm, Center	10	18
LA-WC	A5L01701122	Near Chester	2	2
LA-WN	A5L01731116	West Arm, North	1	1
LA-GS	A5L01761100	Near Gould Swamp	1	1
LA-MC	A5L01761120	West Arm Nr. Mud Creek Mouth	1	4
LA-MX	A5L01891117	Mud Creek Arm above Causeway		1



DRAINAGE AREA & STATION LOCATIONS

PLATE 6

The Department of Water Resources' station numbers in the preceding table are a combination of characters indicating hydrographic area and type of water body, plus latitude and longitude. In explanation, consider the number A5L01071051 which applies to the station near the dam. The components of the number and their derivation are:

A5	-	Feather River Basin
L	-	Lake
0107	-	40° 10.7' Latitude
1051	-	121° 05.1' Longitude

Tabulations of the data generated during the investigation are presented as Appendix A, Water Quality Data Summary, and Appendix B, Field Determinations. The data included in these tabulations cover many limnologic aspects and parameters.

Field Determined Parameters

Many parameters such as pH, dissolved oxygen, and temperature change rapidly and must be determined in the field. The methods used in these activities have been described in Chapter IV.

Temperature

Water temperature is very important in limnology since it affects rates of both biologic activity and chemical reaction, and also affects solubility of oxygen in water. Furthermore, the changes in water density that accompany changes in temperature produce the stratification of deeper lakes and reservoirs.

Vertical profiles of water temperatures were prepared with data gathered from a number of depths at the three major stations. Data from this work are tabulated in Appendix B and presented graphically in Plates 7, 8, and 9. In order to cover a wider time span, data plots from a 1969 study are also presented in this report as Appendix C.

DISSOLVED OXYGEN — TEMPERATURE PROFILES

LAKE ALMANOR, EAST ARM CENTER A5L01431065 (LA-2)

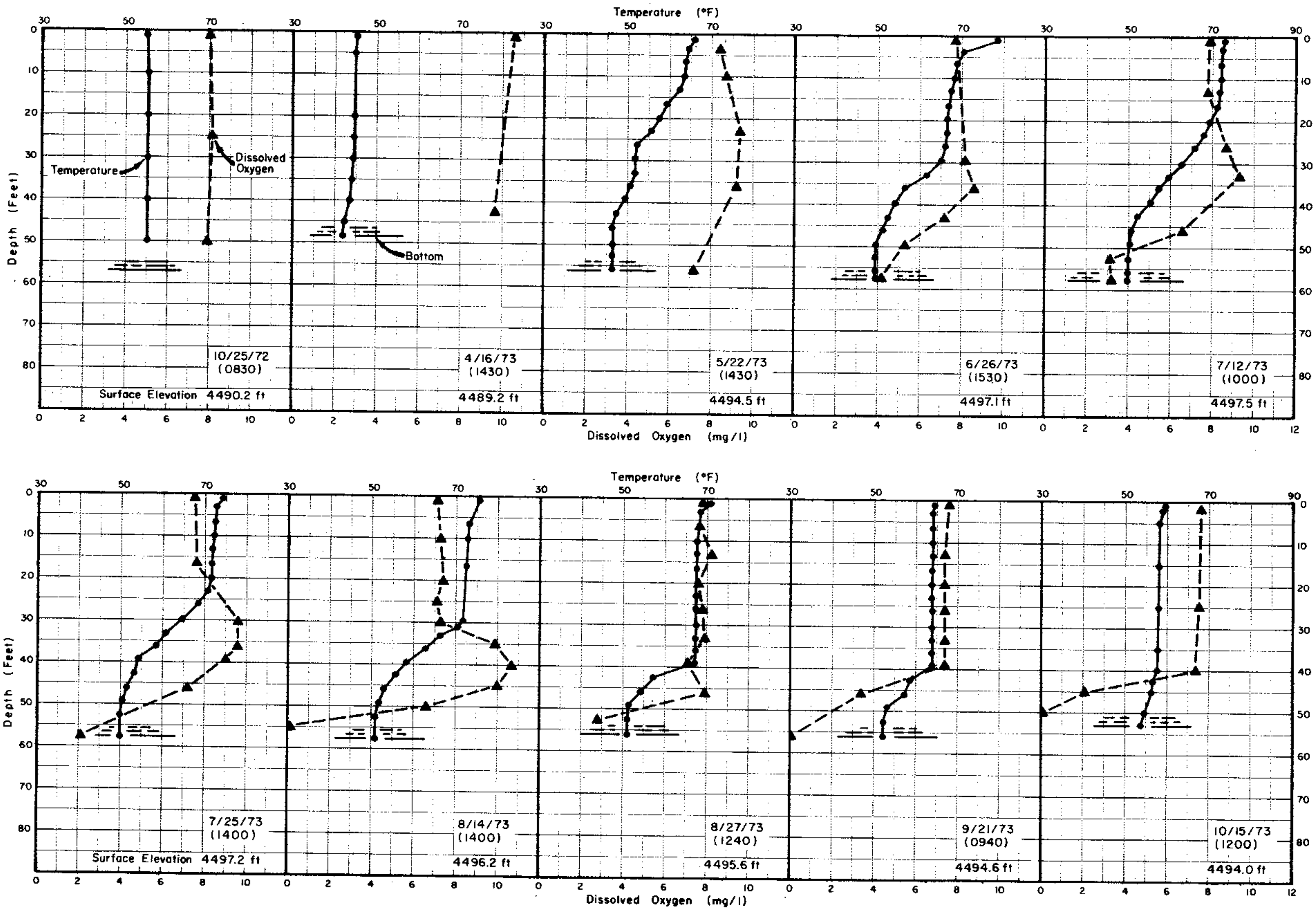
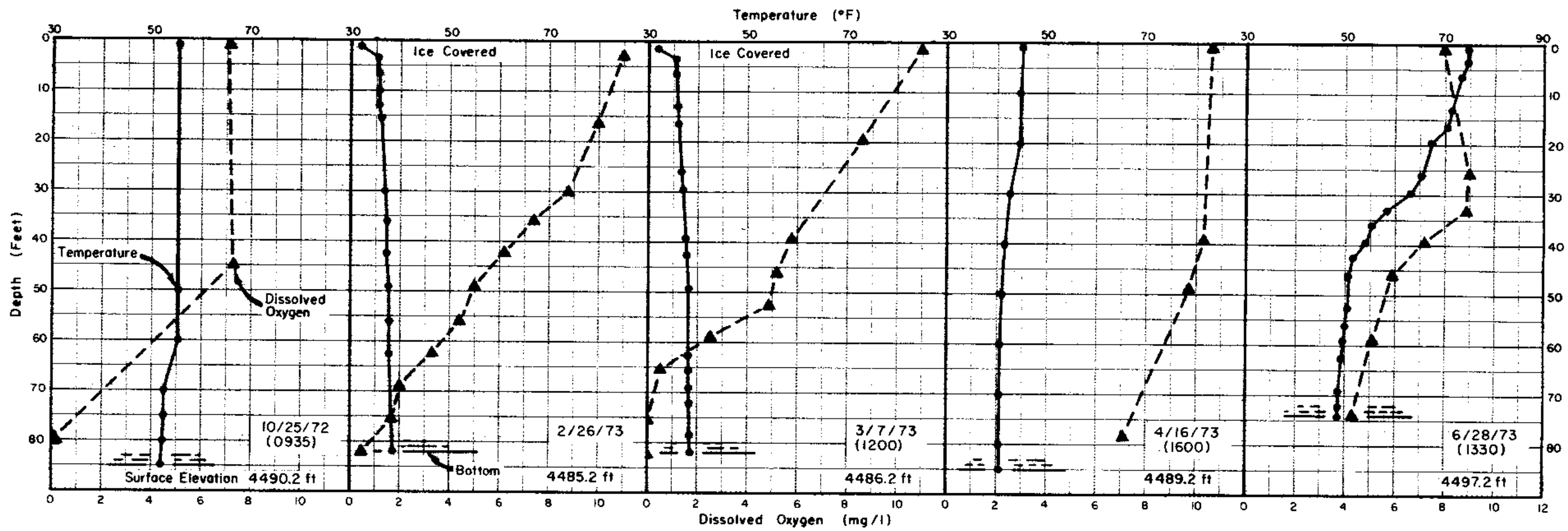


PLATE 7

DISSOLVED OXYGEN — TEMPERATURE PROFILES

LAKE ALMANOR, NEAR DAM A5L0107I05I (LA-4)



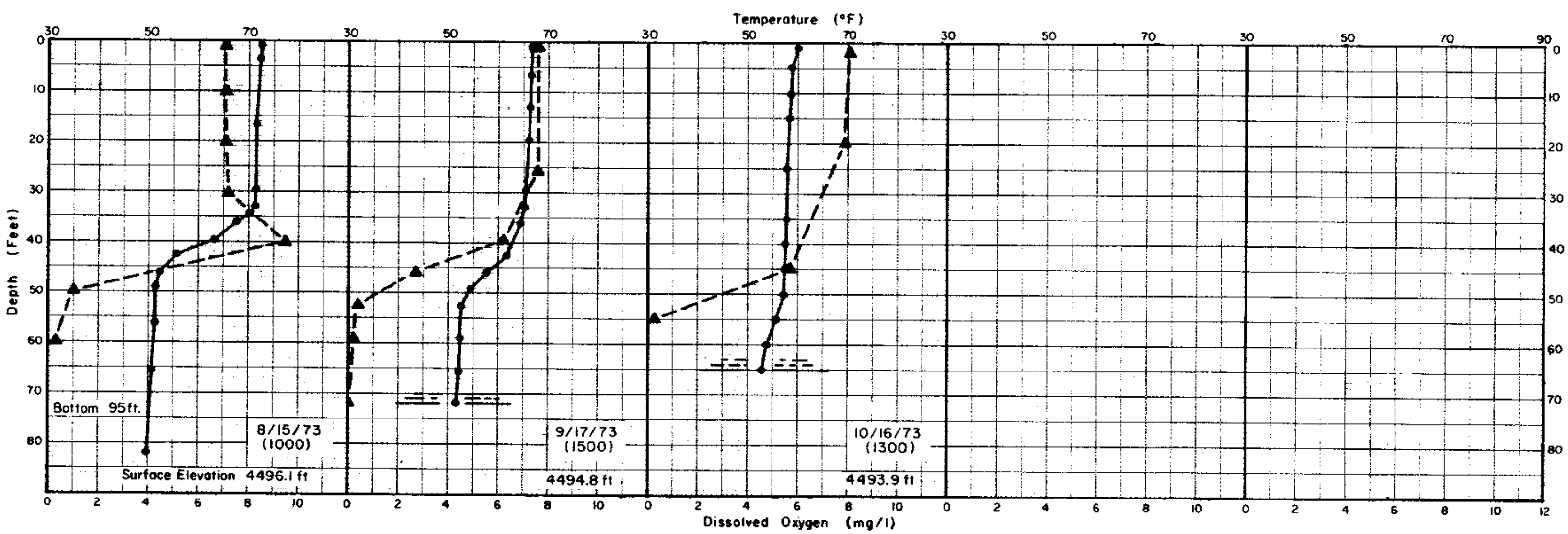


PLATE 8

DISSOLVED OXYGEN – TEMPERATURE PROFILES

LAKE ALMANOR, WEST ARM CENTER A5L0155IIII (LA-6)

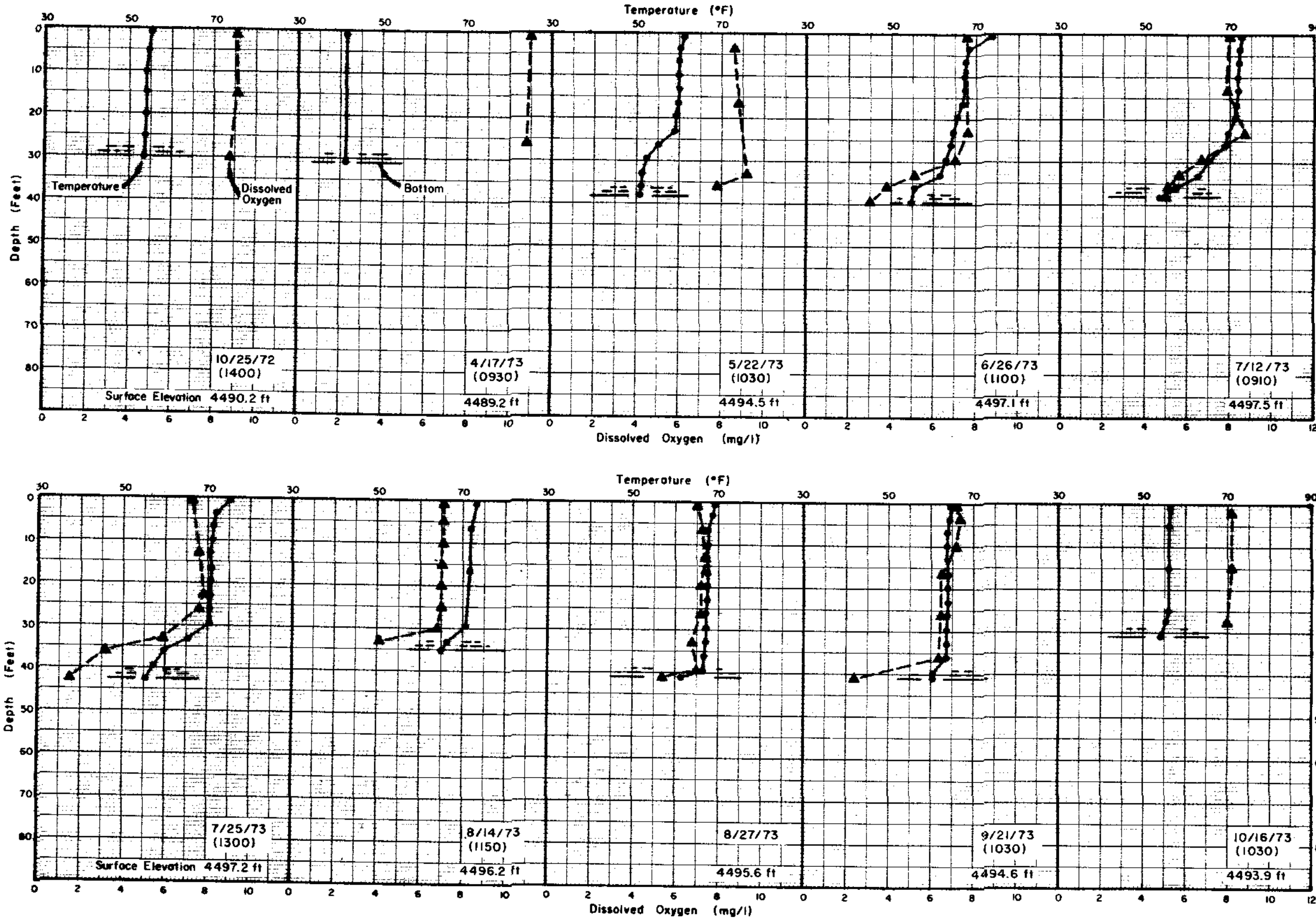


PLATE 9

Air temperature in the vicinity of a reservoir is significant because of the importance of the overlying air as a source of heat to the water. Variations in air temperature, along with variations in wind and cloud conditions, produce the year to year differences of the thermal stratification patterns in a reservoir.

The air temperatures around Lake Almanor in 1973 were above normal in late spring and early summer, as was shown on Table 1. The higher temperatures should have produced a reservoir heat content greater than normal if the cloud conditions and winds occurring during the period were near normal. A comparison of air temperatures in 1973 versus 1969 (a period for which vertical temperature profiles are presented in Appendix C of this report) is made in Table 4. The 1973 air temperatures were significantly higher than those for 1969.

Table 4
AIR TEMPERATURE COMPARISONS (1973 vs. 1969)

Month	Average of Monthly Means for Canyon Dam and Chester		1973 Departure from 1969
	1969	1973	
April	41.0	44.5	+3.5
May	55.2	55.8	+0.6
June	58.8	61.1	+2.3
July	65.6	67.1	+1.5
		Four Month Average Departure:	+2.0

Temperatures are in degrees Fahrenheit.

Source: Climatological Data, California, Volumes 73 and 77, by U. S. Department of Commerce.

Thermal stratification occurred twice during the year of study. The ice cover which formed in early December of 1972 lead to a period of winter stagnation. The ice cover disappeared from the east arm about April 3, 1973, and from the west arm about April 10, 1973. The windy conditions which existed during early April produced nearly complete mixing as the ice melted.

A definite thermocline, by Birges definition[1/], was in existence by May 22, 1973, and continued throughout most of the summer. The epilimnion was deepened and the hypolimnion eliminated in much of the shallower west arm during a late August stormy period. Destratification of the east arm, however, was more prolonged and a significant thermocline still existed on September 21, 1973, but had been eliminated by October 15, 1973.

Dissolved Oxygen

Another parameter which is highly important to nearly all aquatic organisms is dissolved oxygen (DO). Most aquatic organisms have an optimal range of DO and a minumum level below which they will die.

Vertical profiles similar to those for temperature were also determined for DO although at less frequent depth intervals in most instances. Data for DO profiles are also presented in Appendix B and plotted in Plates 7, 8, and 9.

DO conditions for 1972-73 were generally quite satisfactory in Lake Almanor. During the period when the lake was ice-covered, the DO was greater than 6 milligrams per liter (mg/l) in the top 35 feet of water near the dam on both February 26, 1973 and March 7, 1973. At the same times, DO was greater than 6 mg/l in the top 30 feet of water near the Prattville intake tower. On both occasions and at both sampling points the DO was above 11 mg/l near the surface. Anaerobic conditions, however, were found in the lower 10 feet of water near the dam on March 7, 1973.

During the summer stratification, DO conditions were again quite satisfactory. As can be seen from Plates 7-9, the DO was never lower than 6 mg/l in the upper 30 feet of water at the west arm center station. For the east arm center station and the station near the dam, the DO was never below

1/ A thermocline is the zone in a lake where the temperature decreases at a rate equal to or greater than 1°C. per meter of increased depth.

6 mg/l in the upper 40 feet of water, with the exception of March 7, 1973, when it was 5.6 mg/l at 40-foot depth.

DO conditions for 1969, as seen by the plotted data in Appendix C, were similar with relationship to depth at the three major stations as for 1973. An exception occurred at the east arm station on October 7, 1969 when DO dropped below 6 mg/l at about 34-foot depth.

DO requirements of aquatic organisms vary considerably, with certain game fish (especially salmonoids) having some of the highest requirements. Even for the salmonoids a DO level of 6 mg/l should be satisfactory for conduct of most of their life activities. Spawning and incubation and post-incubation are the stages when a salmonoid requires higher DO levels, but these activities usually take place in the waters and gravel beds of flowing tributary streams.

Dissolved Oxygen-Temperature Associations

Although the DO is very important to the higher aquatic organisms, the temperature is also important in determining the suitability of water as a habitat for these organisms. In the case of the salmonoids, the higher temperatures existing near the surface of Lake Almanor during normal summer months are not suitable over a prolonged period. On the other hand, it is common for the DO levels to be the greatest near the surface of a lake.

Because aquatic organisms are affected by both temperature and DO, it is necessary to observe the associated values of these parameters at specific depths. To assist in this consideration, Table 5 was prepared to show the lowest temperatures which were found with various levels of DO. The table was based on data from the station near the center of the east arm because depth at this station is usually sufficient to include a significantly thick hypolimnion during stratification.

Table 5
MINIMUM TEMPERATURES ASSOCIATED WITH
SPECIFIC DISSOLVED OXYGEN LEVELS

Station: Lake Almanor at East Arm, Center; A5L01431065 (LA-2)

	Minimum Associated Temperatures				Minimum Associated Temperatures		
	DO: 7 mg/l °F	6 mg/l °F	5 mg/l °F		7 mg/l °F	6 mg/l °F	5 mg/l °F
Date				Date			
5/8/69	45	45	1/	4/16/73	42	1/	1/
5/20/69	45	1/	1/	4/17/73	44	1/	1/
6/12/69	50	48	46	5/22/73	46	1/	1/
6/24/69	52	48	48	6/26/73	52	51	50
7/7/69	64	54	51	7/12/73	52	50	50
7/18/69	60	52	51	8/14/73	52	52	51
8/12/69	58	55	50	8/27/73	53	52	51
8/21/69	57	56	54	9/21/73	63	60	58
9/2/69	59	57	55	10/15/73	57	57	56
10/7/69	59	59	59				

1/ All DO values on this date were greater than indicated value.

The table shows that fairly low temperatures were associated with all DO levels selected in both periods of coverage. For the duration of both periods, water with 60 degrees or less temperature and 6 mg/l DO was available to mobile organisms, while water with 59 degrees or less temperature and 5 mg/l DO was also available.

Light Transmittance

The extent to which light is transmitted downward from the water surface is very important in determining the depths at which the photosynthetic organisms (phytoplankton and higher plants) can function effectively. Algal physiologists generally agree that the net production of algal material seldom occurs below the level at which incident light is reduced to one percent. The depth at which net production is zero has been designated the "compensation depth".

On August 15, 1973, light transmittance measurements were made at the three major stations. Data from these measurements were converted to percent transmittance and plotted on Plates 10, 11, and 12.

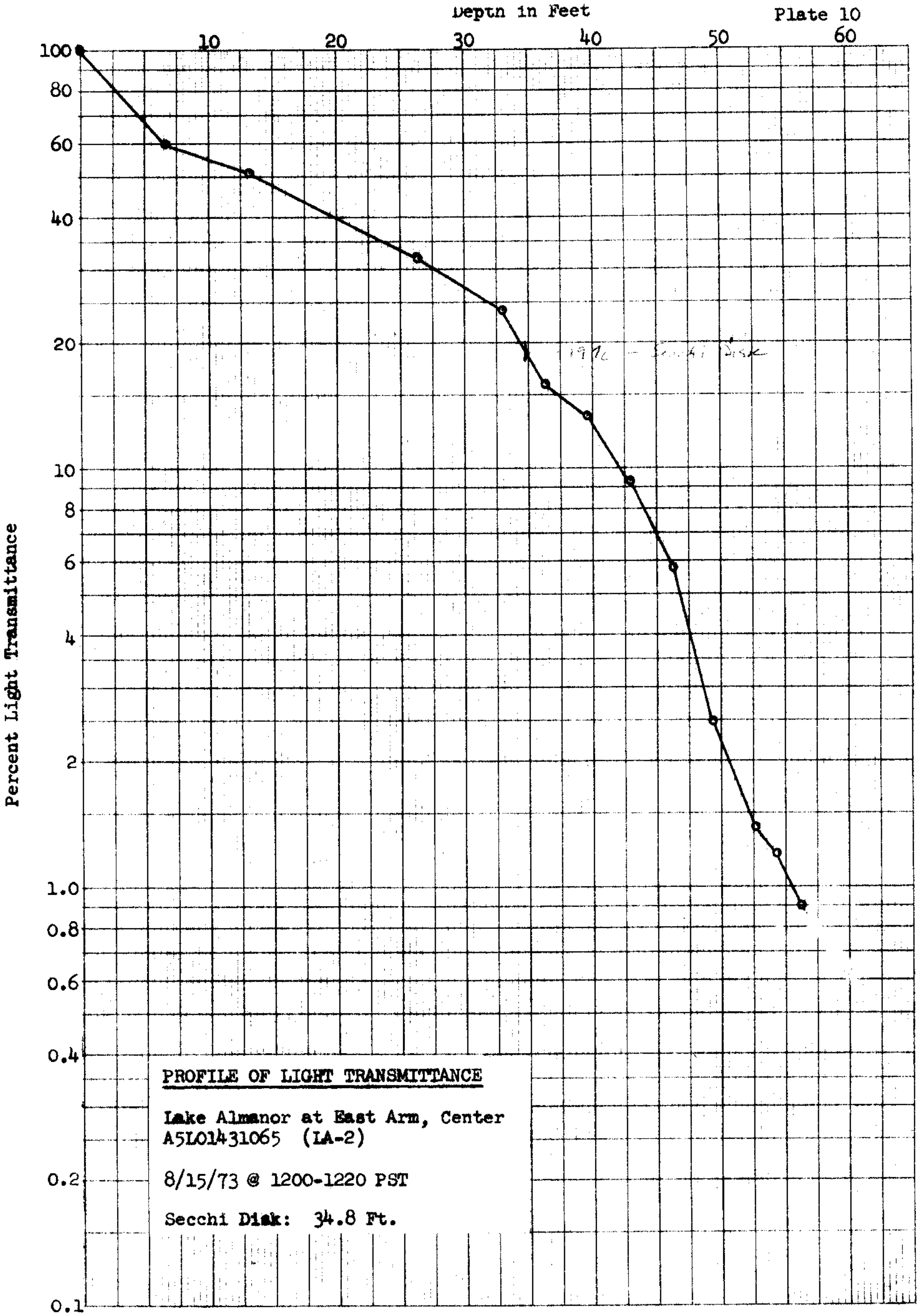
The percent transmittance curves show a change in slope for all three stations. The most pronounced slope change occurred at Station LA-2 in the east arm at about 35-foot depth. Because of these changes in slope, overall coefficient of extinction values were not calculated for the data. One extinction value would apply to the upper portion of the lake where transmittance was greatest, and another value would apply to the deeper portion.

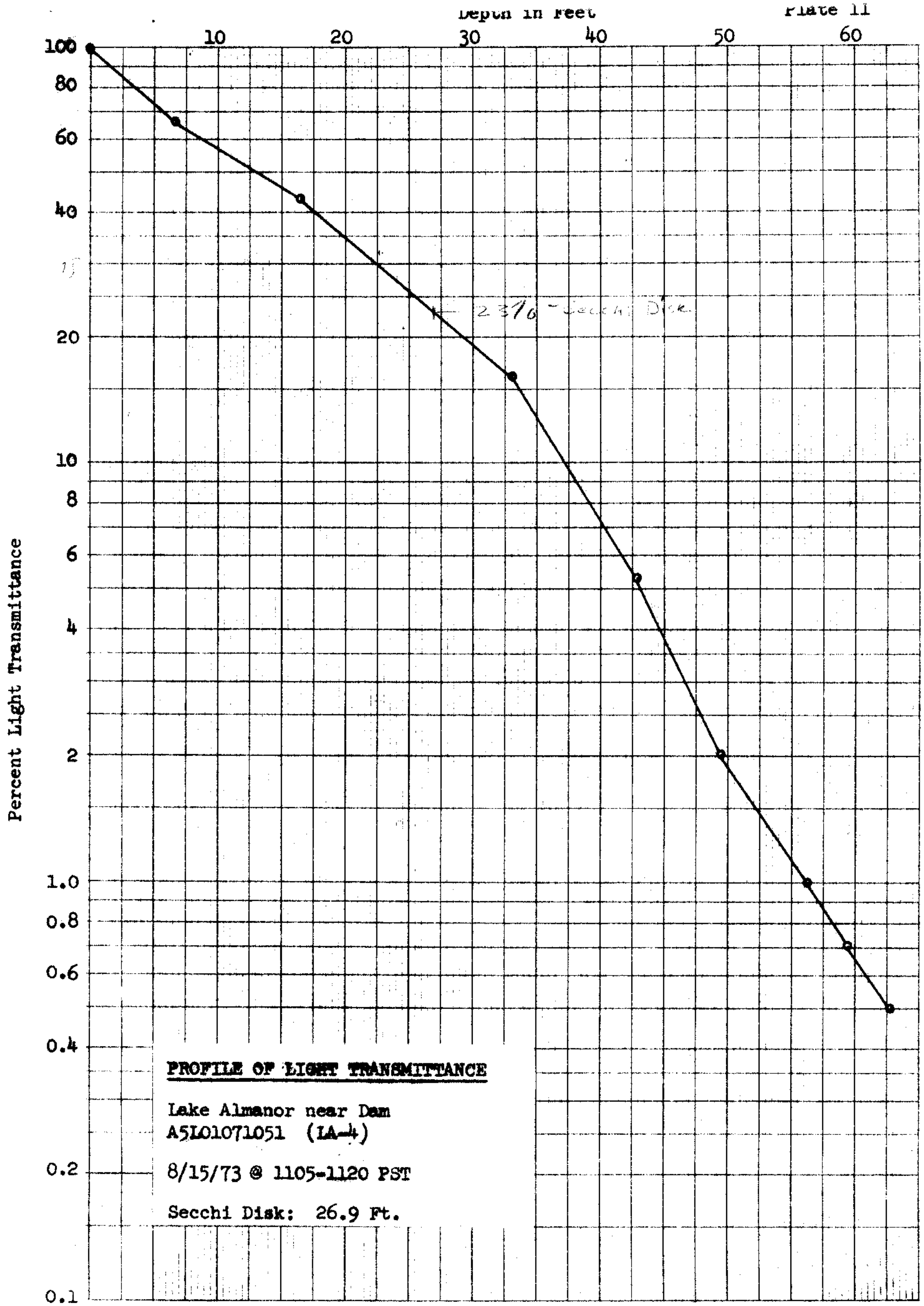
The depth at which the transmitted light had been reduced to one percent of incident light was about 55 feet for Station LA-2 and about 56 feet for Station LA-4. Station LA-6 was too shallow for a 99 percent light reduction, but a 94 percent reduction occurred at 33 feet. In comparison, the one percent light level for Lake Tahoe during 1973 was about at 280-foot depth.

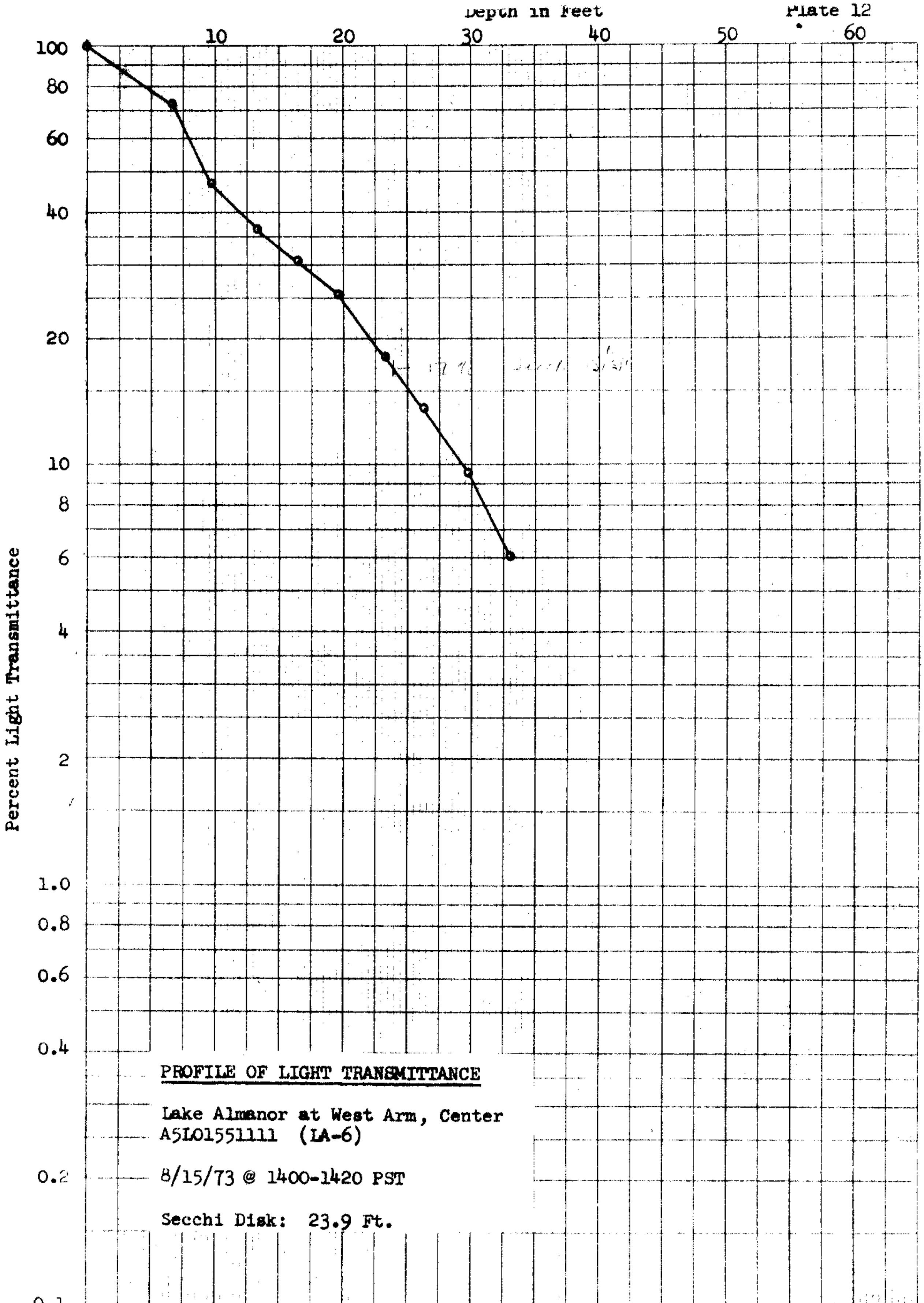
Transparency

Secchi disk readings, as a measure of transparency, give another indication of light penetration into the water. The simplicity of the measurement avoids many of the difficulties which arise during use of a photometer to determine light

Plate 10


Depth in Feet
10
20
30
40
50
60
100
80
60
40
20
10
8
6
4
2
1.0
0.8
0.6
0.4
0.2
0.1
Percent Light Transmittance
1976 - Secchi Disk
PROFILE OF LIGHT TRANSMITTANCE
Lake Almanor at East Arm, Center
A5L01431065 (LA-2)
8/15/73 @ 1200-1220 PST
Secchi Disk: 34.8 Ft.


Depth in Feet
10
20
30
40
50
60
100
80
60
40
20
10
8
6
4
2
1.0
0.8
0.6
0.4
0.2
0.1
Percent Light Transmittance
23% - Secchi Disk
PROFILE OF LIGHT TRANSMITTANCE
Lake Almanor near Dam
A5L01071051 (LA-4)
8/15/73 @ 1105-1120 PST
Secchi Disk: 26.9 Ft.


Depth in Feet
10
20
30
40
50
60
Percent Light Transmittance
100
80
60
40
20
10
8
6
4
2
1.0
0.8
0.6
0.4
0.2
0.1
PROFILE OF LIGHT TRANSMITTANCE
Lake Almanor at West Arm, Center
A5L01551111 (LA-6)
8/15/73 @ 1400-1420 PST
Secchi Disk: 23.9 Ft.

transmittance; however, there are also problems in use of the secchi disk. Such problems include, departure from 12:00 noon, cloudiness, surface disturbances, reflective surface films and the observers visual competence.

A consideration of the secchi disk values included in the tables of Appendixes A and B, show a pattern of seasonal change, with values increasing from spring into summer, then decreasing into autumn. This change was somewhat erratic at the center of the west arm, but in the east arm there was a very steady increase from 13.9 feet on April 17 to 34.8 feet on August 14, followed by a steady decrease to 19.0 feet on October 16. These values may be compared to those of Lake Tahoe which generally fall in the range of 70 - 100 feet. Considering the extreme clarity of Lake Tahoe, the secchi values obtained at Lake Almanor indicates that it is a lake of moderate to high clarity.

Light transmittance values were calculated at the secchi depths on August 15, 1973, for Stations LA-2, LA-4, and LA-6. They were respectively 19 percent at 34.8 feet, 23 percent at 26.9 feet and 17 percent at 23.9 feet.

pH Values

The pH values obtained during the investigation fall mostly into the range 7.0 - 8.0, slightly above neutrality. When one considers that these values were in association with DO where percent saturation ranged from 0 - 124, a wider range of pH values might have been expected. The narrowness of the pH range is possibly the result of the buffering action of the bicarbonate ion which is such a predominant anion of the dissolved mineral content of Lake Almanor.

Specific Conductance

The extent to which an electrical current passes through water increases as the concentration of dissolved ionic materials increases; therefore, a measurement of specific conductance or electrical conductivity (EC) of a water

gives an indication of dissolved solids content. Because of this relationship, the results of EC determinations are discussed with total dissolved solids.

Nutrients

Because of the importance of nitrogen and phosphorus to the photosynthetic aquatic organisms, these elements are frequently termed "nutrients". Since these organisms form the food base for the biologic systems of all lakes, the extent to which the nutrients are available has great influence on the level of biologic activity in any lake.

Sources

Included in the sources of nutrients to a lake are soils and rocks of the basin, bottom materials of the lake, precipitation on the lake and its watershed, and wastes from man's activities. Tributary streams are the means of transport for the majority of the nutrients entering most lakes, and unless significant quantities of wastes are discharged to the streams, most of these nutrients originate with basin runoff.

With an imaginary line drawn from the point of the peninsula to the southerly shore, the drainage areas for the two arms of Lake Almanor thus delineated are very nearly equal. An estimate of the total runoff into the westerly arm, however, is nearly half again as large as that for the easterly arm. This is because of the higher annual precipitation in the northwesterly part of the Lake Almanor drainage basin.

Four of the major streams tributary to Lake Almanor were sampled for nutrients on May 22, 1973 -- a time when moderate runoff from snowmelt was occurring. Since the fall rains were cut short by the occurrence of early snows

in 1972, sampling of the tributaries during the rainy season was not practical. Data presented in Appendix A show that nitrate-nitrogen concentrations ranged from 0.02 to 0.03 mg/l, which are rather low levels for streams. Total nitrogen was also low as all values were between 0.1 and 0.2 mg/l.

Of four stream samples analyzed for phosphorus, the sample from North Fork Feather River with 0.01 mg/l orthophosphate phosphorus was the only one with positive values reported. Samples of two streams contained measurable total phosphorus but only at the levels of 0.02 and 0.01 mg/l.

The two streams with measurable total phosphorus were the only ones with turbidities $\geq$ 1 turbidity unit. Since the total phosphorus analysis is run on unfiltered samples, a high percent of the phorphorus reported was probably attached to, or a part of, the suspended materials. Most of these suspended materials would eventually settle out in the lake and some would be overlain with other settling materials; therefore, the availability to phytoplankton of the phosphorus carried with the suspended material is uncertain but probably even more limited than the analyses indicate.

Inundation of land and its soils, vegetative cover and organic debris, can also be a source of nutrients. Following dam alterations made prior to 1963, the average minimum surface area was increased about 4,500 acres, a 25 percent increase in bottom area. The flushing action of the short retention time (1.1 years) of Lake Almanor should have reduced this nutrient source to a minor current influence.

A second type of inundation results from seasonal fluctuations of the reservoir. Along the westerly shore of the west arm and in the Mud Creek Arm, the soils contain much organic materials and support some vegetative cover. These peripheral flatlands probably contribute some nutrients during periods of inundation.

In a report prepared for the Lake Tahoe Area Council, precipitation in the vicinity of Lake Tahoe was estimated to contain 0.4 mg/l of combined nitrogen. The precipitation falling directly on Lake Almanor is approximately 8 percent of the water discharged from the lake; therefore, a nitrogen concentration of 0.4 mg/l in the precipitation would contribute 0.03 mg/l nitrogen to the overall contents of the lake. Phosphorus levels in precipitation are generally considered to be insignificant.

Nitrogen fixation can also be a significant source of combined nitrogen in a lake. This fixation can result from the presence of certain species of bacteria or blue-green algae. Bacteria were not studied in this investigation. Blue-green algae were seldom found in significant quantities throughout most of the lake; however, a rather heavy bloom of Anabaena was observed in the isolated portion of Mud Creek Arm and a moderate bloom of what appeared to be blue-green algae was observed in the Hamilton Branch Arm.

The high volume of blue-green algae which occurred in Mud Creek Arm during the study may have resulted from (1) nutrients rich tributary inflow, (2) nutrient addition through inundation of fecal materials from cattle and waterfowl, or (3) higher water temperatures caused by shallowness could have given advantage to blue-green algae. Because of the complex inflow pattern of Mud Creek Arm, no attempt was made to collect nutrient samples of the inflow. It is probable, however, that the water in Mud Creek Arm comes from the tributaries rather than the backing in of water from the west arm, since runoff from the Mud Creek Arm drainage area was estimated to be several times the maximum storage capacity of the arm.

Availability and Critical Levels

The importance of nutrient availability to the photosynthetic organisms of a lake is such that many attempts have been made to determine the minumum

concentrations of nitrogen and phosphorus which may lead to overproduction of phytoplankton. Because of the difficulty of accurately determining the amounts of nutrients available in a lake, and because of the many factors other than nutrients which also influence such overproduction of algae, conclusions concerning such minimums have been quite varied. Most established values include total nitrogen levels considerably less than one mg/l and phosphorus levels at or near 0.01 mg/l.

The minimum concentrations mentioned above concern the overproduction of algae. Lesser concentrations of nutrients should, therefore, be sufficient to develop a level of algal production adequate as a food base for a satisfactory sports fishery.

Results

Determination of nutrient levels in Lake Almanor was attempted during this investigation by the analysis of samples collected at five different times from a total of eight stations. The range of values and simple statistical analysis of the data are presented in Table 6.

Table 6
STATISTICAL SUMMARY OF NUTRIENT CONCENTRATIONS (mg/l)

	Combined Nitrogen as N					Phosphorus	
	NO_3	NH_3	Inorganic	Organic	Total N	Ortho	Total
No. of Analyses:	(31)	(31)	(31)	(31)	(31)	(32)	(32)
Maximum:	0.08	0.89	0.89	0.3	1.19	0.01	0.08
Minimum:	0.00	0.00	0.00	0.1	0.14	0.00	0.00
Median:	0.00	0.01	0.03	0.2	0.24	0.00	0.01
Mean:	0.017	0.069	0.086	0.2	0.29	0.003	0.014
No. of Analyses Less than Indicated Value: $\frac{(No.)}{(Value)}$	$\frac{29}{<0.05}$	$\frac{28}{<0.10}$	$\frac{28}{<0.14}$	$\frac{26}{<0.3}$	$\frac{29}{<0.32}$	$\frac{23}{<0.01}$	$\frac{29}{<0.04}$

Evaluation of the data is complicated by the many factors involved in sample collection, in laboratory analysis, and in selection of criteria for determining biologic significance. Selected sampling depths should be pertinent to nutrient availability in the euphotic zone (region of net productivity) during the major growing season of May through October. Nutrients incorporated in the algae dispersed in the sample, however, may not be completely extracted. On the other hand, a sample from a layer with extra high phytoplankton populations, may yield analytic results much too high, with only partial extraction of nutrients in the algal mass. Seasonal pulses of algal growth add complications through greater or lesser incorporation of nutrients in algal bodies. Although little photosynthetic activity is likely in the hypolimnion, the decomposition of settled algae produces nutrient concentrations in that zone which are higher than in the rest of the lake.

Complications described above probably had their least effect during the March 7, 1973, and April 17, 1973, sampling days. Samples collected after breaking through the ice cover on March 7, 1973, should have contained low phytoplankton volumes due to shortness of days, low sun angle, light reduction by cover of ice and snow and the low water temperatures. At a station near the Prattville intake tower (LA-IT) inorganic nitrogen (-N) at 7 feet depth was 0.00 mg/l and organic-N was 0.2 mg/l, while DO was near saturation. At 28 feet, about 6 feet above the bottom, inorganic-N was 0.17 mg/l and organic-N 0.1 mg/l, with DO about 50 percent of saturation (about 6 mg/l).

The winter data from the station near the dam (LA-4) showed inorganic nitrogen of 0.04 mg/l and organic nitrogen 0.2 mg/l at 10 feet depth, with DO about 80 percent of saturation. The sample from 75 feet (about 10 feet off the bottom) had no dissolved oxygen but inorganic nitrogen (nearly all ammonia) was 0.65 mg/l and organic 0.2 mg/l.

The orthophosphate-P value of 0.01 for the 28-foot depth at Station LA-IT was the only analysis greater than 0.00 for either station. No total-P was found at the shallow depth of either station, but the deep samples gave results of 0.04 for LA-4 and 0.01 for LA-IT.

Conditions for nutrient sampling on April 17, 1973, were probably better than for all the other sampling times. The ice had gone out of the east arm about two weeks earlier and out of the west arm about a week prior to the sampling date. Strong winds during the period had mixed the lake quite well and had kept it mixing as indicated by the vertical uniformity of several parameters. The one to two weeks mixing period gave time for reoxygenation throughout most of the vertical column and allowed chemical activities to stabilize somewhat. The period of continued mixing along with low water temperatures also contributed to the low levels of phytoplankton volume in the lake at the time.

A total of five nutrient samples were collected at different depths from the stations near the dam (LA-4) and near the center of the east arm (LA-2). The analytical results for these samples showed much uniformity considering the fact that the values were near the low end of analytic capability. Mean values for the five analyses were: inorganic-N = 0.11, organic-N = 0.14, orthophosphate-P = 0.004 and total-P = 0.008.

Three samples were collected from different depths near the center of the west arm (LA-6). The means of these analyses were somewhat different from those at LA-2 and LA-4. These mean values were: inorganic-N = 0.04, organic-N = 0.15, orthophosphate-P = 0.007 and total-P = 0.01.

Results of the March and April samplings are helpful in evaluating the nutrient conditions of Lake Almanor. Fairly high concentrations of ammonia and total phosphorus developed at lower depths during winter stagnation. The

spring mixing, however, caused the redistribution of these nutrients to the point that the concentrations became rather low. These levels of nutrients at spring overturn should not be sufficient to cause undesirable algal conditions in the major open portions of the lake.

Other Dissolved Minerals

The minerals dissolved in a body of water are important both to aquatic organisms living in the water and to persons withdrawing the water for some beneficial use. Those minerals whose dissolved concentrations are usually the highest (sodium, calcium, chloride, bicarbonate, etc.) are often of less concern limnologically than are those termed nutrients. Determination of specific concentrations of these more abundant minerals was not emphasized in this investigation. In a few instances "standard mineral" analyses, as discussed in Chapter IV, were made, giving fairly complete coverage to these various minerals.

More frequently, partial mineral analyses were made which included total hardness (calcium and magnesium), alkalinity (carbonate and bicarbonate), and specific conductance or electrical conductivity (EC). Observation of comparative changes in the few more frequently analyzed items, along with the occasional "standard minerals", gives a fairly comprehensive picture of all the various mineral constituents for the period of the investigation.

Total Dissolved Solids

The total dissolved solids (TDS) content in water can be determined by evaporating a filtered sample to dryness and weighing the mineral matter which remains. Because of the time involved in this analysis, the correlation between TDS and EC is frequently used to advantage. The simple EC analysis can give a good approximation of TDS values and can be used to easily compare differences in the mineral content of samples from different depths, different stations, or different times.

During the investigation, 29 samples received laboratory analysis, and EC values ranged from 119 to 79 micromhos (umhos) with a median of 98. Since 25 of the values were within 8 percent of the mean, there was apparently little change in total dissolved minerals during the period of investigation. Furthermore, EC values of 89 and 85 were obtained for Lake Almanor samples collected on June 10, 1953 and September 2, 1969, respectively, indicating that the lake is usually consistent in dissolved mineral content.

A factor for converting Lake Almanor EC values to TDS was calculated as 0.60. Since only 5 TDS values were available for use in the calculation, the factor can only be considered approximate.

These EC values are quite similar to those of Lake Tahoe and to many of the reservoirs which receive drainage from the northern Sierra Nevada and the Cascade Range. The Lake Almanor EC values, however, are roughly one-third (or less) of those commonly existing in Lake Berryessa, Clear Lake, and other lakes and reservoirs fed by drainage from the Coast Range.

Hardness

The mean value of 21 samples analyzed for total hardness is 39, a relatively low value. Correlation of the mean hardness with the mean EC yields a percentage reactance value of about 80 for the hardness ions (Ca^{++} and Mg^{++}) which indicates that the sodium percentage is about 20 or less. The total hardness content of the water, if withdrawn or released from Lake Almanor for domestic purposes, would be rated "soft". Furthermore, most of the hardness could be removed by boiling because of the strong predominance of the bicarbonate ion among the anions. The low percent sodium values of the water would produce little sodium hazard if these waters were used for irrigation.

Alkalinity (Bicarbonate)

The mean bicarbonate value of the 26 samples analyzed for alkalinity is 58. Correlation with the mean EC gives a percent reactance value for bicarbonate of about 97. This indicates that nearly all of the negative ions in the water are bicarbonate ions.

Other Mineral Constituents and Metals

A search of current and historic data yielded five "standard mineral" analyses for Lake Almanor. These analyses are presented in Table 7. Values from this table corroborate the percentage reactance values derived earlier and show low concentrations of chloride and sulfate. Because of the low sulfate values, concentration of hydrogen sulfide should be fairly low in the hypolimnion, and the toxic effects of this compound should be minimal.

Included in the table are data from the analysis of two samples for total copper and total zinc. The samples were collected near mid-depth during the 1973 spring overturn and should be representative of the concentrations of the whole vertical column. Concentrations for the west arm were 0.01 mg/l for copper and 0.02 mg/l for zinc while both metals were 0.00 mg/l for the center of the east arm. Since the analyses were a "total" type, some of the metals reported may have been incorporated with suspended material and would have been lost to the water column when the suspended materials later settled to the bottom. The low concentrations reported seem unlikely to cause any harmful effects in aquatic organisms.

TABLE 7
ANALYSES OF SURFACE WATER

Date and time sampled P.S.T	Depth Sample / Bottom (ft.)	Temp in °F	Specific conductance (micromhos at 25°C)	pH	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Fluoride (F)	Boron (B)	Silica (SiO_2)	Other constituents	Total dissolved solids in ppm	Percent sodium	Hardness as $CaCO_3$ Total ppm	Hardness as $CaCO_3$ N.C. ppm	Analyzed by
					Mineral constituents in parts per million / equivalents per million																	
Mountain Meadows Reservoir near Dam (A5L01701014)																						
4/26/56		52	57	6.4	5.4	2.7	2.1	0.6	0	31	0.5	0.0	0.3	0.0	0.00	11	Fe 0.5	38	15	25	0	DWR
Lake Almanor East Arm, Center (A5L01431065) (LA-2)																						
4/17/73 1415	25'	44	99	7.5	8.1	4.9	3.7	1.2	0	59	0.8	0.1	0.2		0.1		Fe 0.05 Mn 0.21 Cu 0.00 Zn 0.00	76		40	0	DWR
Lake Almanor near Dam (A5L01071051) (LA-4)																						
6/10/53		56	89	7.8	8.9	3.7	4.5	1.0	0	55	2.1	0.8	0.5	0.0	0.01	6.8		48	15	37	0	DWR
9/2/69 1830		70	85	7.8	8.3	3.8	3.0	1.5	0	51	1.6	0.7	0.0		0.0			50		36	0	DWR
10/25/72 1000	45' 88'	52	100	7.2	10.0	3.9	3.9	1.4	0	59	0.0	0.0	0.0		0.0			52		41		
Lake Almanor West Arm, Center (A5L01591113) (LA-6)																						
4/17/73 1010	18' 31'	41	93	7.5	8.1	3.9	3.7	1.2	0	54	0.6	0.4	0.1		0.0		Fe 0.08 Mn 0.04 Cu 0.01 Zn 0.02	56		36		DWR

CHAPTER VI

BIOLOGIC CHARACTERISTICS

The aquatic organisms which inhabit a lake are especially important to the inplace use of the lake. The make-up of the overall biota which develops in a lake is determined to a large extent by types and amounts of plants which grow there.

Photosynthetic Organisms

Aquatic organisms capable of producing food through photosynthesis support, either directly or indirectly, nearly all the remaining organisms living in most lakes. The overall biologic productivity of a lake is therefore highly dependent on the photosynthetic populations which include both phytoplankton and higher order plants.

Phytoplankton

The term phytoplankton only implies that the members of the group are suspended plant organisms incapable of moving against water currents; however, the term is commonly applied only to those organisms capable of photosynthesis, that is algae, but is not applied to bacteria.

Phytoplankton analysis included identification and organism count to genus, as well as a volume calculation for each genus. The reporting method, except for major genus which is reported separately, is to report the total organism count and total volume for all the genera found in each of four large algal groups (blue-green, green, flagellates, and diatoms). These data are tabulated in Appendix A. Bar-graphs of the total volumes of each of the four algal groups are presented in Plates 13, 14, and 15.

PHYTOPLANKTON VOLUMES -- MAJOR SAMPLING STATION

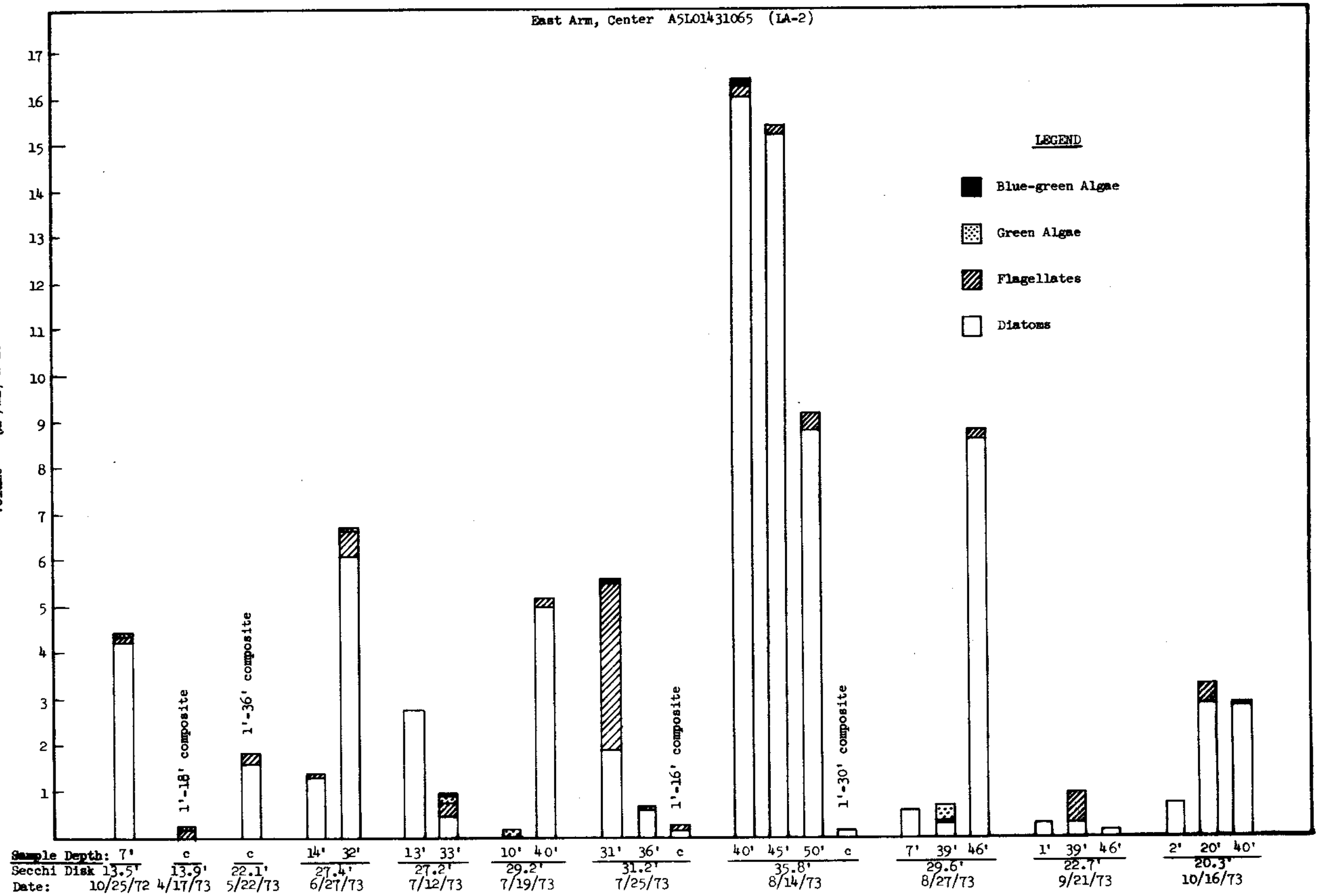


PLATE 13

PHYTOPLANKTON VOLUMES -- MAJOR SAMPLING STATIONS

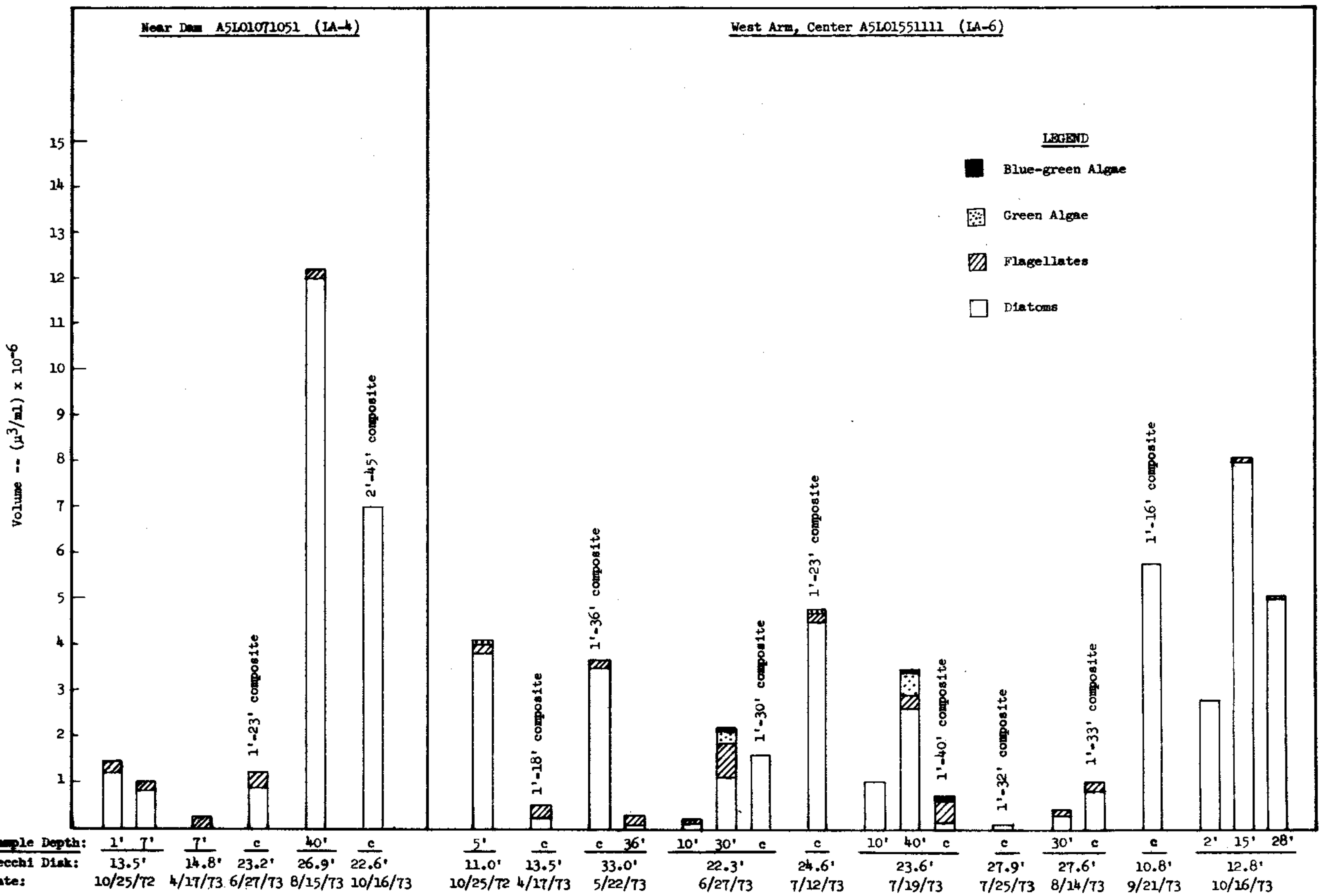
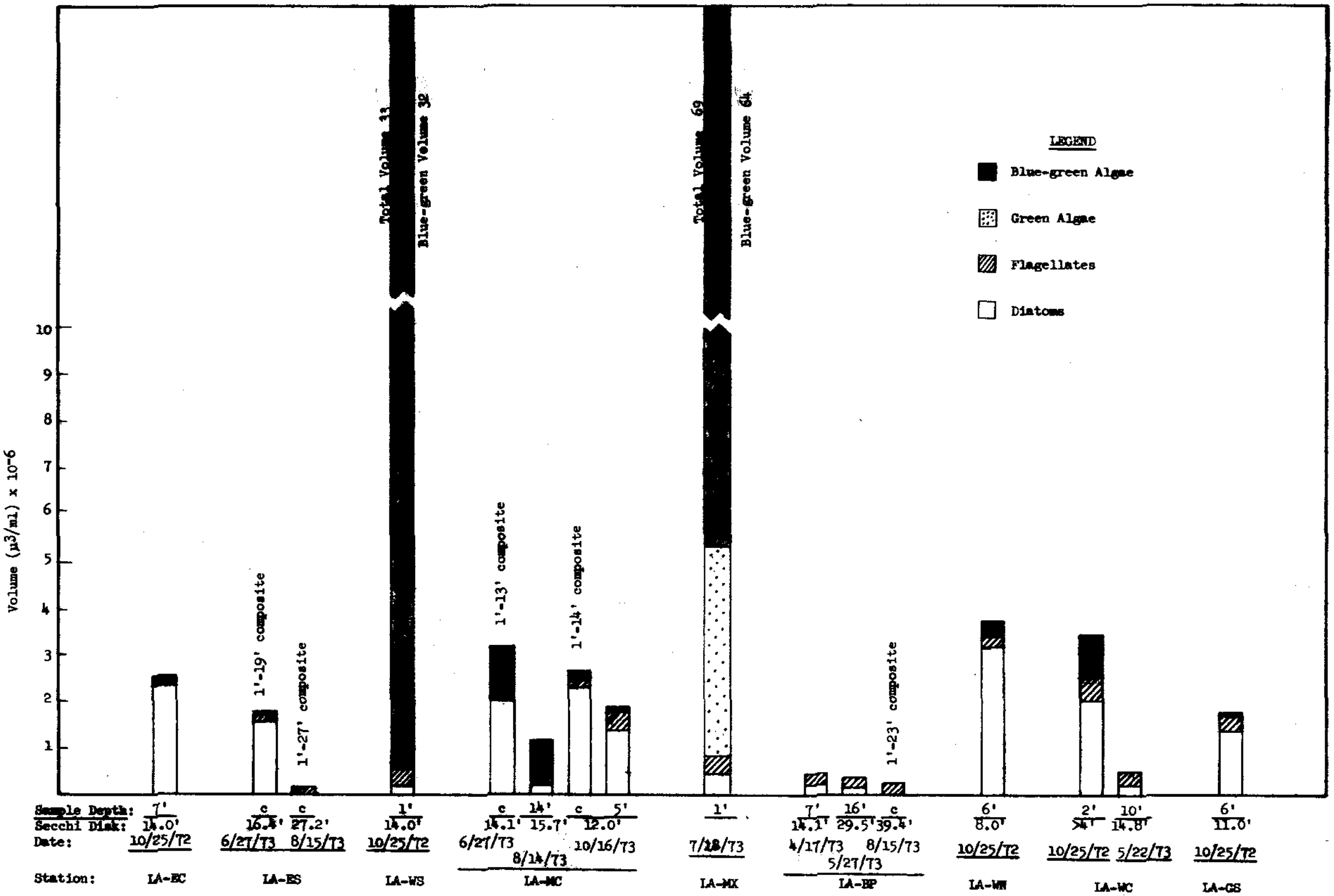


PLATE 14

PHYTOPLANKTON VOLUMES -- MINOR SAMPLING STATIONS



The data in bar-graphs indicate that significant amounts of blue-green algae and green algae were seldom found in the major portions of the lake. There were two instances when very large volumes of blue-green algae were reported. In the first instance, a small localized bloom in the southerly part of the west arm was observed and sampled on October 25, 1972.

The second instance of blue-green algae significance was the algal bloom in Mud Creek Arm upstream of the causeway which was observed in late June and early July of 1973. On the sampling trip of July 19 a phytoplankton sample was collected by reaching out from the easterly shore of that arm. Visual observation at the time of sampling indicated that the bloom had passed its peak.

Because of the manner in which the sample was collected, the reported phytoplankton volume of 69,000,000 μ^3/ml cannot be considered representative of that entire arm of the lake. It does, however, indicate the occurrence of a sizeable bloom.

Since the existence of the bloom was apparent from the distance of the causeway road, there must have been a heavy concentration near the surface -- a common location for blue-green algae. Laboratory results showed that Anabaena, a blue-green algae, made up more than 90 percent of the total phytoplankton volume. Similar blooms have been observed in this arm at about the same season during several previous years.

Plates 12 through 14 show that the total volume of the flagellates were frequently a significant portion of the total volume, but the actual amounts were seldom great. The frequent predominance of diatoms, however, can be easily seen. There were 39 laboratory analyses on which the reported total phytoplankton volume equaled or exceeded 1,000,000 μ^3/ml (1 mg/l). Of these

there were 23 instances where diatoms constituted 90 percent or more of the total, and 34 instances where diatoms were 70 percent or more of the total.

A consideration of the total volumes reported indicates the occurrence of several pulses of moderate to moderately high levels of phytoplankton production during 1973. The duration of these pulses comprised much of the May through October growing season.

The occurrence of one of these pulses and many of the concurrent limnologic conditions were observed and well documented on August 14 and 15, 1973. The August 14 data from the station near the center of the east arm is presented graphically on Plate 16.

This plate shows that the major portion of the bloom was located in the thermocline and upper hypolimnion. Although the location of this bloom seems somewhat unusual, the high degree of agreement of all the reported parameters supports its existance at that depth.

The deep secchi disk transparency of 34.8 feet supports the low values of fluorescence and phytoplankton volume reported for the upper 30 feet. The near saturation levels of DO, as shown by departures from saturation, for this portion of the water column further supports the low phytoplankton values.

The greatest phytoplankton volume was 16,000,000 μ^3/ml which occurred at 40-foot depth. The fluorescence values at 35 and 40 feet also showed large increases over those existing in the upper 30 feet. The DO departures from saturation also showed large positive increases at 35 feet and 40 feet.

Fluorescence reached its maximum at 50 feet, while volume and DO departure from saturation had dropped off significantly at this depth. This indicates the presence at this level of phaeophyton (pigment in dead algae) settled from the large populations above and of algae inefficient in photosynthesis due to age or the diminished level of available light.

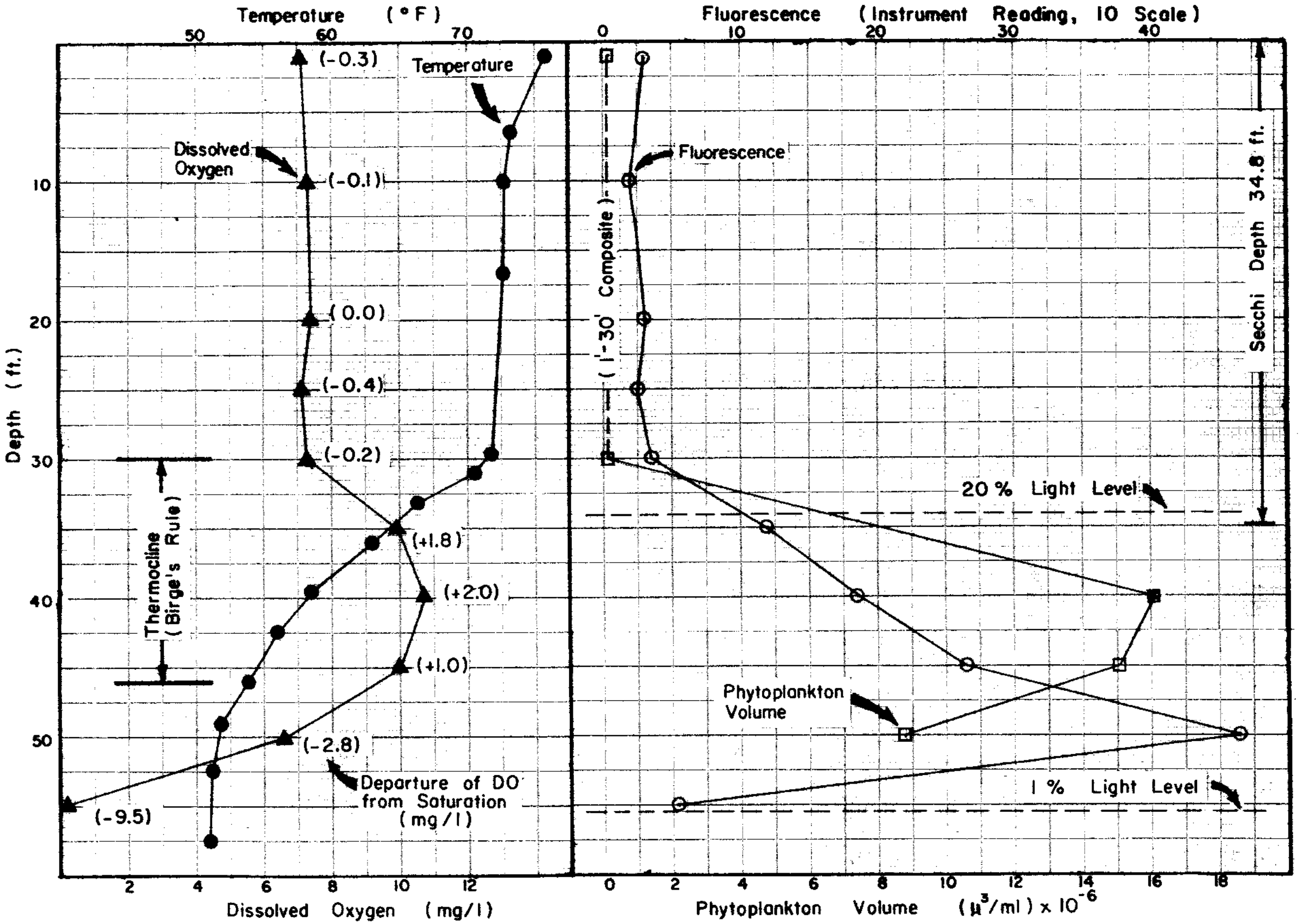


PLATE 16

LIMNOLOGIC CONDITIONS OF EAST ARM, CENTER (LA-2) ON 8/14/73 (1330-1500 PST)

There are several possible causes for the existence of this algal bloom so deep in the water column. One of these is that nutrients could have accumulated at this depth as a result of the settling and subsequent decay of earlier phytoplankton populations. Since phytoplankton volumes significantly greater than 1,000,000 μ^3/ml occurred as early as May 22, 1973, there had been nearly three months for this accumulation to take place.

A second reason for the location might be the lower concentration of available light at these depths. The light incident to the surface had been reduced to 20 percent at the 34-foot depth.

A third possible reason for location of the bloom in the thermocline is the cooler water there. Diatoms made up 95 to 99 percent of the total volumes reported for the 40, 45, and 50-foot samples, and these algae are often found in colder water.

Vascular Aquatic Plants

In addition to the phytoplankton, the higher order aquatic plants also carry on photosynthesis and can, therefore, be significant to the overall biologic productivity of a lake. These plants either float at the surface with no attachment to the bottom, or they have roots with which they are attached to the bottom. Free floating plants are commonly found in warmer waters and in waters with limited wind activity.

Bottom attached plants (water weeds) can become quite dense and cover a high portion of shallow lakes. An example of such growth was reported in Lake Davis during 1970 when water weeds, mostly Leafy Pondweed, covered all areas of the lake, with depths less than 15 feet, which was about 40 percent of the surface.

General observations of bottom attached plants in Lake Almanor were made during this investigation. Although there were some areas in the shallower parts of the west arm where these plants made a dense surface cover, they did not appear to cover large portions of the lake. In some areas these plants showed only sparsely to moderately dense distribution. Identification of these plants was not made during this investigation.

Primary Productivity

A major objective of this investigation was the evaluation of overall biologic productivity of Lake Almanor. The major part of this evaluation is the determination of primary productivity (photosynthetic activity) of the lake. This photosynthetic activity should constitute a high percent of the food base for the biota of Lake Almanor since externally produced food sources are quite minor.

The commonly used light and dark method for determining primary productivity was attempted twice during this investigation. The first attempt, based on measurement of DO changes, indicated a very low rate of production, but this may have been the result of collecting the water from depths with limited volumes of phytoplankton since the volume data frequently showed large variations for different depths.

The second attempt used the radioactive carbon-14 technique. Because of extremely rough weather during the incubation period, many of the sample bottles were lost, but the results from those remaining can provide some qualitative information on algal production in the lake. Table 8 lists the counts of radionuclide decay obtained from filtered algae samples from various depths at two Lake Almanor stations. The counts are total radioactive decays for a present time interval and thus provide only relative productivity estimates.

Table 8
RADIOACTIVE COUNTS FROM PRIMARY PRODUCTIVITY TEST
July 19, 1973
(5 min. counting interval)

Sample Depth (Ft.)	Station LA-2	Station LA-6
0	3,100	
5	4,400	
10	5,500	
15		11,000
20	6,700	
25		
30		19,000

Looking only at relative differences, it appears that the algae in the west area were producing more biomass (organic material) during the test period and that productivity increased with depth. The effect of depth on algal growth is related to the extinction of light through water, and apparently the light levels in the surface waters are so high as to be inhibitory to the algae. Unfortunately the deep samples were lost at both stations and the expected decrease in productivity at the extreme depths was not demonstrated. The lack of sufficient data prevented the calculation of productivity in terms of grams carbon fixed/M^2/day, but the values would be quite low.

Although the light and dark bottle methods proved unsatisfactory, another indication of primary productivity can be derived from evaluation of phytoplankton volume data. When samples are collected from a sufficient number of depths at representative stations, meaningful standing crop figures can be calculated. If these samples are collected on several dates throughout the growing periods, the standing crop values give a good indication of phytoplankton production.

Standing crop calculations were made from the phytoplankton volume data from one sampling date in each month from May through October. Two types of calculations were made, with the first being a determination of the mean phytoplankton volume which would result if the organisms could be homogeneously redistributed throughout the entire contents of the lake. The second calculation was a determination of the volume of algae existing under an average unit of surface area (centimeter^2).

The results of the above calculations are presented in Table 9. Included in the table are similar calculations for Lake Davis and Frenchman Lake, as well as average secchi depths for all three lakes.

Standing crops for Lake Almanor cannot be compared to those of the other two lakes on a strict basis since samples were collected from much fewer depths at the other lakes. The limited number of sampling depths for Davis and Frenchman could have resulted in failure to analyze samples from the most productive zones of the lake in some instances. The sampling depths for these lakes tended to be shallow, but the shallow secchi depths indicate that the phytoplankton were probably located in the shallower waters.

A further limitation is placed on the Lake Davis data since little work has been done to establish the fraction of food base for the fishery which is derived from the primary productivity of the large crop of water weeds which grows in that lake.

In spite of the limited comparability of the data from the three lakes, the fact that the Lake Almanor values were consistently higher by a significant amount indicates that photosynthetic production in that lake probably equals or exceeds that found in the other two lakes.

Table 9

STANDING CROP COMPARISONS

Lake Almanor (1973), Frenchman Lake (1972), and Lake Davis (1972)

Month	Standing Crop of Total Lake Contents $\left(\frac{\mu^3 x10^{-6}}{ml}\right)$			Standing Crop For Unit Surface Area $\left(\frac{\mu^3 x10^{-6}}{cm^2}\right)$			Average Secchi Depth of Stations Sampled (Ft.)		
	Lake Almanor	Frenchman Lake	Lake Davis	Lake Almanor	Frenchman Lake	Lake Davis	Lake Almanor	Frenchman Lake	Lake Davis
May	2.2	0.5	0.4	2420	490	240	28	11	15
June	1.7	0.5	0.1	1960	500	85	25	8	22
July	2.0	0.8	<0.1	2310	800	<20	26	8	16
August	3.1	2.6	0.4	3530	2440	270	32	6	7
September	1.3	1.1	0.9	1430	1030	550	17	9	10
October	3.5	0.4	0.5	3810	410	300	16	8	10

Comparison of algal production in Lake Almanor can be made in another way, by calculating the highest mean phytoplankton volume of the water column for any given station during the growing season. The highest mean values calculated in this manner were 4,300,000 μ^3/ml for the center of the east arm and 5,300,000 μ^3/ml for the center of the west arm. By comparison, the highest mean value for any of the stations sampled in Clear Lake during 1972 was 13,000,000.

The maximum mean water column phytoplankton volumes were moderate to high as were the standing crop values throughout the entire growing season. For these reasons, the phytoplankton productivity should be adequate to support a fairly substantial biota.

Other Aquatic Organisms

Zooplankton

Zooplankton tows were made at a few Lake Almanor stations to determine the general types of zooplankton present and some idea of the total amounts present. As described earlier, vertical tows were made at each station from three feet off the bottom to the surface. Table 10 contains a summary of the zooplankton data collected in the Lake Almanor study.

The zooplankters were identified to major grouping only but each group included genera common to the lakes of California, including *Daphnia* and *Bosmina* (Cladocera), *Diaptomus* and *Cyclops* (Copepoda), and *Kellicottia* and *Keratella* (rotifers). The values in Table 10 are reported in terms of quantity per M^3 (1000 liters) instead of the normal liter, a commonly used convention in oceanography and limnology because of the relative scarcity of zooplankton.

The limited number of samples collected precludes any sophisticated analysis of the data but a few general conclusions can be drawn. There were no

Table 10
ZOOPLANKTON RESULTS FOR LAKE ALMANOR

Date / Length of Tow (ft.)	ORGANISM COUNTS (Organisms / m^3)					Suspended Solids (mg/m^3)	Volatile Solids (mg/m^3)
	Cladocerans	Copepods (A)	Copepods (N)	Rotifers	Total Zooplankton		
	East Arm, Center A5L01431065 (LA-2)						
6-26-73 / 52'	4,280	3,060	5,660	6,120	22,120	50	44
7-19-73 / 46'	3,770	2,210	2,720	270	8,970	15	13
8-14-73 / 53'	1,200	5,780	5,900	600	13,480	63	51
	Near Dam A5L01071051 (LA-4)						
8-14-73 / 53'	1,370	1,640	17,220	270	20,500	59	44
	West Arm, Center A5L01071051 (LA-6)						
6-26-73 / 35'	7,950	7,490	9,080	7,920	32,440	93	79
7-19-73 / 36'	1,740	3,670	1,850	910	8,170	94	75
8-14-73 / 31'	2,370	7,580	4,400	2,800	17,150	96	86
	West Arm near Mouth of Mud Creek A5L01761120 (LA-MC)						
6-26-73 / 11'	6,500	7,580	6,500	3,610	24,190	83	72
8-14-73 / 12'	4,130	2,640	4,130	4,130	15,030	55	45

apparent significant differences in zooplankton concentrations among sampling stations on any sampling date. However, there was a significant difference between concentrations of zooplankton collected on either June 26, 1973, or August 14, 1973, and those collected on July 19, 1973. The two pulse seasonal cycle of zooplankton abundance is commonly found in lakes and appears to be related to algae growth. Goldman et al (1968) demonstrated a similar cycle in Lake Maggiore, Italy, where peak zooplankton numbers were on June 15 and August 1, with a mid-summer low around July 1. There is not a good correlation between zooplankton abundance and algal volumes found on any particular sampling date, but this is not surprising since peak zooplankton concentrations normally lag behind algal blooms.

The numbers of zooplankton are moderate in terms of other lakes. In Lake Tahoe, a rather non-productive ecosystem, DWR (1970) reported a maximum of about 6,000 organisms/M^3, with most values at all stations being less than 2,000 organisms/M^3. In data from Lake Maggiore, Italy, a moderately eutrophic (fertile) lake, total numbers of zooplankton ranged between 10,000 and 160,000 organisms/M^3, with the peak values generally greater than 50,000. Indications from the data are that these levels of zooplankton, organisms which are important food organisms for juvenile salmonoids and other fish, should be adequate to support a fairly substantial fish population in Lake Almanor.

Benthic Organisms

Only three qualitative benthic samples were collected during this study, one each at the center stations of the east and west arms and one near the mouth of Mud Creek. The data are shown in Table 11.

The types of organisms included in the table are common to most lake systems and all can be used as fish food at some stage of their life cycle.

Table 11
BENTHIC ORGANISMS OF LAKE ALMANOR

Organism	Station Location: Center East Arm (LA-2)	Center West Arm (LA-6)	Near Mud Creek Mouth
Midges			
Tendipeditae		24	34
Culicidae	51	28	1
Aquatic Worms	157	18	3
Snails			4
TOTAL	208	70	42

CHAPTER VII

FISH PRODUCTION

Historic and Existing Production

In the absence of historical records of fish production only general statements of our knowledge of Almanor can be made. Based on data collected in 1971 and some extrapolation, we estimated the standing crop of all species at 80 pounds per surface acre. The composition of the limnetic (open water) assemblage was about one-half game fish and about one-half rough fish. The species composition of Almanor was very different in the early days of Almanor but the total standing crop was probably not much different than now. There has been a shift from the dominance of carp and Lahontan redside shiners (a small minnow occupying the littoral and limnetic zones), by biomass, to the present abundance of chubs, kokanee, and suckers.

Relationships of Production and Limnology

Other Lakes

Jenkins (1967) concluded from multiple regression analysis of several environmental factors on standing crop of fishes and sport fish harvest that the factors exerting the greatest positive influence were total dissolved solids (TDS) and shore development[1/]. (Environmental factors considered were reservoir area, mean depth, TDS, storage ratio, shore development, age, water level fluctuation, outlet depth and growing season). To a lesser extent, increased storage ratio had a positive effect on sport fish harvest and a negative effect on standing crop. The age of a reservoir, mean depth, and surface area all showed negative influences on sport fish harvest. Growing season had a positive, but low correlation, effect on standing crop.

1/ Shore development is defined as the ratio of the length of the shoreline of a lake to the circumference of a circle of equal area.

In a survey of water chemistry of Minnesota lakes and ponds, Moyle (1956) concluded that increased concentrations of total phosphorus, total nitrogen, total alkalinity, and salinity (as an index to TDS) were all strongly related to increased standing crops of fish. Moyle further concluded that lakes of increasing fertility (and standing crop) were associated with the transition from coniferous forests to hardwood forests to the prairie. Phosphorus in addition to being an indicator of standing crop was indicative of the type of fish community present. The optimum phosphorus concentration associated with lake trout was about 0.02 ppm, with pike-perch about 0.035 ppm, with centrarchids about 0.05 ppm, and with carp about 0.1 ppm.

In an analysis of multiple factors affecting the standing crops of fishes in 41 lakes, Hayes (1964) found that 67 percent of the variability in the "Productivity Index" (standing crop) was accounted for by area (20 percent), depth (29 percent) and alkalinity (18 percent). Alkalinity accounted for only 3 percent of the variability in standing crop in a single factor analysis.

Brylinsky (1973) concluded after analyzing 55 widely scattered lakes and reservoirs that, overall, factors related to the nutrient medium influenced primary productivity less than factors related to solar energy input. However, nutrient concentrations were more important in reservoirs of similar latitude (where latitude is equivalent to growing season in Jenkins' work). Furthermore, Brylinsky found that lake morphology had little influence on primary productivity per unit area.

Lacking in Brylinsky's study and most productivity studies, however, is an examination of the link between primary production and fish production, yield, or standing crop.

Lake Almanor

The yield of sport fish as an index to fish production in Almanor is unsatisfactory for comparative purposes because sport fish harvest is closely related to fishing intensity. Almanor's total angler use of just over one man-day per surface acre is very light when compared to the national average of 10.9 man-days per acre in 1966 (Stanberry, 1967).

Nutrient availability, and ultimately the availability of food organisms to fish, is inversely related to the mean depth for a given amount of nutrients in a system. This relationship, and the importance of total solar input, when applied to Almanor with its large surface area and shallow depth, would suggest a high degree of utilization and turnover of available nutrients.

It is probable that Almanor's concentration levels of phosphorus, nitrogen, and carbonate related nutrients are near optimum for a salmonid fishery. Any significant increase in the levels of nitrogen and especially phosphorus would probably cause a shift from conditions suitable for trout and salmon to conditions more suitable for the centrarchid-cyprinid assemblage. This situation would be further aggravated if summer stagnation in the hypolimnion were made more severe and of longer duration because of increased nutrient concentrations. This latter possibility would further restrict the available salmonid habitat in the summer and reverse the progression of the past few years from cyprinid to salmonid domination of the limnetic zone.

A more extensive and longer lasting oxygen deficient hypolimnion would probably drastically alter the benthic community of Almanor and the fish communities utilizing the benthic food resource.

Reduced water clarity associated with increased primary productivity and nutrient concentrations would probably have little direct effect on the plankton feeding fishes such as the chubs and kokanee. Reduced water transparency, however, could greatly hinder the foraging ability of the predaceous game fish such as bass, trout, and coho salmon.

In Summary, there are no reliable predictive models of reservoir limnology and fish production that allow for quantitative predictions of standing crops of fishes. There is, however, sufficient knowledge of limnological relationships to predict that with increased nutrient entry into a system there will occur an increase in the fish biomass and a shift from a salmonid assemblage to less desirable species.

CHAPTER VIII

MANAGEMENT CONSIDERATIONS

The dams which impound the majority of existing reservoirs were built primarily for water supply, downstream flood protection, hydroelectric power generation or for some combination of these purposes. All of these benefits are realized beyond the vicinity of the impounded reservoir. In recent years it has become more and more evident that the benefits derived from in-place use of a reservoir for aesthetic purposes, for fishing, and for other recreational activities can equal or exceed the long established major benefits.

Planners have readily accepted these in situ benefits for inclusion in benefit-cost ratio determinations. It seems, however, that there has been a lag in establishing and carrying out the reservoir management practices necessary for the maximization of these in situ benefits. One possible reason for this is the lack of adequate funding systems for such management activities.

Each reservoir is more or less unique in its many characteristics, such as, configuration, mean depth, retention time, geographic location, climate, and dissolved mineral content. All of these aspects help produce the final limnologic conditions of a lake. There are also certain watershed characteristics such as topography, geology, vegetative cover, precipitation, and man's activities which influence limnologic conditions.

Because of the complexity of the above mentioned influential characteristics, the management practices for one lake and its watershed may be considerably different from those for another. Establishment of a suitable management system for a given lake, therefore, can result only from a complete consideration of the many aspects involved.

Evaluation of Basin Characteristics

Watershed features have only an indirect effect on the limnologic conditions of a lake, but since the lake exists only as a result of the runoff from the watershed, the quantity, quality, and timing of this runoff is very important. These three aspects of the runoff are affected both by natural watershed characteristics and by man's use of the watershed.

In order to understand runoff characteristics, the various items affecting it should be studied in this manner: (1) existing data should be searched out and accumulated; (2) accumulated data should be tabulated, processed, and evaluated; and (3) new data should be obtained in areas indicated by evaluation of existing data.

Although these data would be developed primarily for use in conjunction with the reservoir, they should also prove useful to indicate the potential for beneficial use of the streams as fisheries and recreation areas.

Climatologic and Hydrologic Information

The isohyetal lines as presented on Plate 2 were prepared as part of the broad Central Valley area. Refinement of these lines may be possible. A verification test against recent data would be advisable. Such a test might indicate the desirability of establishing one or more new climatologic stations in the basin. The installation of a recording anemometer at the lower end of the peninsula would be of much value.

Streamflow measurement is necessary to determine the quantities of inflow being contributed by different sectors of the basin, but there is presently little inflow data for the streams tributary to Lake Almanor. A flow measurement program should be established; however, a minimal station network and a short period of operation might prove satisfactory.

Water quality data of basin streams is also necessary in order to show how the basin is affecting the water quality of the lake. Samples should be collected during key periods of runoff and analysed for electrical conductivity, turbidity, alkalinity, nutrients (nitrogen and phosphorus), and other constituents deemed necessary. The usual field determinations should also be made. Continuous maintenance of such a monitoring program might not be necessary, but the sampling intervals should be of a frequency and duration sufficient to show any changes which might be occurring.

Geology, Topography, and Soils

Geologic formations which exist in a basin are important for their mineral make-up, their topographic conformations, and for the soils which develop over them.

The geologic formations of the Lake Almanor basin are identified and delineated on the Westwood Sheet of the Geologic Map of California. This map was published by the California Division of Mines and Geology in 1960. Since the scale of the map is 1:250,000, it does not provide detail. Additional geologic study may be necessary in certain areas where development is occurring or planned. The California Division of Mines and Geology has unpublished geologic mapping of the study area at map scales of 1:48,000 and 1:62,500 which could be used in future studies.

The rock types included in the basin influence the water quality of surface runoff in contributing dissolved minerals. Man's use of the basin does not usually affect this mineral contribution except in the case of certain extensive mining activities.

The topography of the basin is presented on seven quadrangle maps of the 15-minute series prepared by the United States Geological Survey.

These maps and their contour intervals are listed below:

Lassen Peak	80'
Mt. Harkness	80'
Chester	40'
Westwood	40'
Jonesville	80'
Almanor	80'
Greensville	40'

Conversion of the contour maps to a slope type presentation might be desirable in at least certain areas.

A mantle of soil exists over a large part of the basin. Since there has been no extensive soil survey in this area, little information concerning basin soil types is presently available. Such information is quite important in land use planning, and a soil survey should be conducted.

Land Classification and Land Use

As part of a statewide program of the California Department of Water Resources, a detailed survey of land use of the Lake Almanor watershed was conducted during 1963. A classification of land types was also made by the Department in 1964. The land classification did not include a detailed determination of soil types.

Natural Resources

In developing information concerning the watershed, a comprehensive inventory of natural resources should be prepared. The existance of these resources determine to a large extent the types of activities that man will pursue in the basin. Although some aspects of these resources might be included in some of the other accumulations of information, a specific inventory of these resources would be useful.

Planning for Land Use Regulations

Careful consideration and study should be given to the acquired watershed information. These studies should lead to the development of plans for regulation of present and future land use. These regulations should be developed to minimize the harmful effects which can result from man's use of the basin; however, the regulations should be only a part of an overall effort to protect all the environment.

Soil Disturbance

Soils are often disturbed as a part of such land development activities, as road building, homesite preparations, and logging. Soil disturbance may lead to many undesirable effects in surface waters. Turbidity may be increased, resulting in aesthetic degradation, and the reduction of photosynthetic productivity. Sediments may be deposited causing harm to spawning gravels and loss of reservoir storage space. Additional dissolved minerals may be added to the waters, thus reducing their quality.

Soil types of the basin should be studied along with the land slope and protective cover. Methods for conducting soil disturbing activities in different situations should be developed and regulations regarding these practices should be adopted.

Waste Generation and Disposal

Wastes are frequently produced as a result of man's activities with sewage and domestic solid wastes being two of the most familiar examples. Other wastes are also produced by many different activities, such as logging, construction, livestock production, lumber production, and recreation.

Disposal of wastes can be achieved by many means, some of which may produce harmful effects on the environment. In many instances, surface waters are the environmental element showing the greatest degradation. Since most surface waters of the basin ultimately reach Lake Almanor, most of these degradations will appear to some extent in the lake.

There is not a large volume of sewage currently being produced within the basin since the basin population is estimated to be about 4,000 persons. The majority of these persons, however, live in the immediate vicinity of Lake Almanor. Disposal of sewage from homes outside Chester and Westwood is through septic tanks and leach fields.

Because of the difficulty in determing the level of nutrients available to photosynthetic organisms of a lake, it is not easy to establish the levels at which overproduction of algae will result. For this reason, significant new contributions of nutrients must be considered as a potential threat to any lake with moderate levels of phytoplankton production.

At present, the treatment of sewage by the two communities in the basin and by the individual septic systems is in most instances reducing the content of organic material and bacteria to a satisfactory level. There is, however, only limited reduction of nitrogen and phosphorus. If the basin population increases significantly, special efforts may be necessary to prevent the additional sewage from causing undesirable nutrient levels in the lake. The suitability of soils for leach field disposal of sewage should be given careful consideration when new installations are proposed since failure of these systems produce health hazards and provide little nutrient reduction.

Waste disposal in the basin is under the regulatory authority and surveilance of the California Regional Water Quality Control Board, Central Valley Region. Basin management planning should be coordinated with the policies and actions of this Board.

Other Activities

The wide variety of man's activities produce many different effects on the environment, and some of these effects are not easily recognized. Planning for protection of the environment in these instances is difficult. Special consideration should, therefore, be given to any proposal for major changes in land use in order to detect these more subtle environmental effects.

Reservoir Operation and Management

The use of all large reservoirs for multiple benefits is desirable; however, these differing uses and their related management practices are sometimes in conflict with one another. The greatest benefit from a reservoir can only be achieved through establishment of an operational and management plan which minimizes these conflicts.

The Lake Almanor dam and reservoir came into existance for the single purpose of hydroelectric power generation. The present owner of the reservoir, Pacific Gas and Electric Company, still utilizes it for that purpose. Any new management practices must, therefore, be compatible with operation for power generation.

Withdrawals and Releases

The timing and rates of releases from a reservoir are quite important since they affect the surface elevation, and most in situ uses of the reservoir are in turn affected. The present release schedule for Lake Almanor is such

that a surface elevation satisfactory for all fishery and recreational purposes exists a high percent of the time. The fluctuations of surface elevation are indicated in Plates 4 and 5 and in Table 12.

Table 12
AREA-STORAGE-DEPTH CORRELATIONS FOR LAKE ALMANOR

Reservoir Stage	Storage (Acre Feet)	Surface Area (Acres)	Surface Elevation (Ft.)	Average Lake Depth (Ft.)
Spillway Lip	1,308,000	28,257	4,510	46
Max. Normal Storage	1,039,941	26,275	4,500	40
Avg. Max. Storage (1964-1973)	977,000	25,629	4,498	38
Avg. Min. Storage (1964-1973)	606,000	21,200	4,482	29

The levels from which water is withdrawn from a reservoir is quite important to the limnologic conditions. Deep withdrawals during summer periods can reduce the volume of colder water in the hypolimnion. Shallower withdrawals, however, cause warmer water to be released, which can affect the downstream receiving waters.

At present, water is normally withdrawn from a rather deep portion of Lake Almanor. Since the fishery of the lake is intended to be a cold water type, decreasing the depth of future withdrawals for temperature control might prove desirable.

The temperature data developed during 1969 and 1973 did not indicate a need for such depth change; however, years during which the surface elevation was at lower levels might produce different temperature profiles. Mean depth on August 15, which is the date when the reservoir's heat content nears its peak, for the years 1964 through 1973 is shown in Table 13. The mean depth for 1969

and 1973 were 38.4 and 37.1, respectively. For the above reasons, further temperature studies should be made to better evaluate the desirability of reducing withdrawal depths.

Table 13
NET CONTENTS OF LAKE ALMANOR
ON AUGUST 15 (1964 - 1973)

Year	Net Contents (Acre Ft.)	Surface Elevation (Ft.)	Surface Area (Acres)	Mean Depth (Ft.)
1964	726,500	4,487	23,000	31.6
1965	905,500	4,495	24,860	36.4
1966	649,200	4,484	21,800	29.8
1967	929,700	4,496	25,112	37.0
1968	704,300	4,486	22,600	31.2
1969	989,500	4,498	25,773	38.4
1970	982,800	4,498	25,701	38.2
1971	1,004,000	4,499	25,920	38.7
1972	811,800	4,491	23,858	34.0
1973	932,500	4,496	25,140	37.1

Dissolved Oxygen Control by Aeration

Salmonoids, the major sports fish of Lake Almanor, require cooler water and higher levels of DO than many other fish. For this reason, the desirability of artificial aeration of the colder water, therefore, needs consideration.

At all times during the warm periods of 1969 and 1973, these fish could have found water suitable in both temperature and DO content. The association of dissolved oxygen and temperature are discussed in Chapter IV.

Because satisfactory conditions existed during those years, aeration would not have been needed.

It is quite possible, however, that higher levels of phytoplankton growth could occur in the early part of a growing season, causing higher DO demands in the hypolimnion when the algae settled and decayed. In a year when winds were less, these DO demands could become even greater since currents in the epilimnion would be reduced and a greater percent of the phytoplankton would settle into the hypolimnion before decaying. In such instances, artificial aeration of the hypolimnion might be desirable.

The most commonly used aeration system is quite simple in design and relatively inexpensive to install and operate. The principle components of the system are an adequately sized air compressor with hose connection to diffuser heads or perforated tubes which are suspended at the desirable depth. This system can produce significant increases in DO only if sufficient air is injected to cause mixing of the reservoir.

Since the above system produces destratification and mixing, its use will result in an increase of the water temperature at the depth where air is injected. This is because the mixed water column above the injection point develops a nearly uniform temperature approximately equal to the average temperature of the water mass above the injection point prior to aeration.

In addition to the initial warming of the deeper water, additional temperature increases can be expected if aeration is repeated later. This is because the near-surface waters, which are still being subjected to the heating influence of solar radiation and warm overlying air, again assume their earlier temperatures. This heating of the surface results in an increased average temperature of the water mass, and subsequent mixing will again produce temperature increases in the deeper waters. With continuous or frequently repeated aeration, the entire water mass above the diffusers approaches the surface temperatures.

As a consequence of the mixing from this simple aeration method, the minimum temperatures of the aerated water would be the average temperature of the mixed water mass. Average temperatures for the upper 60 feet of water in Lake Almanor during mid-August of 1969 and 1973 were 66° F. and 68° F., respectively. The average temperature of the entire water mass of Lake Almanor on August 15, 1973, was 67° F. The surface temperatures in mid-August were 73° F. in 1969 and 74° F. in 1973.

Based on the above considerations, the use of an aeration system which produces mixing would produce temperatures in the aerated water far above those which are optimum for salmonoid fish. The use of this type aeration in Lake Almanor seems inadvisable, excepting those instances when loss of the salmonoid population seemed imminent or late in the season when natural cooling could be expected within a short time.

If future conditions of associated temperature and DO in Lake Almanor were to indicate the desirability of aeration of the cooler waters, the less common aeration methods which try to avoid mixing should be investigated. In Fish Bulletin 141 of the California Department of Fish and Game two references are made to persons who have worked on the development of nonmixing hypolimnetic aerators. These persons are, H. Bernhardt of Sieburg, Germany and R. E. Speece of New Mexico State University. A technical presentation of Bernhardt's work appeared in the August 1967 issue of the Journal of the American Water Works Association.

Control of Rooted Plants

Bottom attached aquatic plants (water weeds) often become a nuisance in shallow portions of lakes. Since much of the west arm of Lake Almanor is shallow, heavy growths of water weeds could develop at some time. Future growth

of these plants should be closely observed, and control measures should be considered if they do reach nuisance levels. Control measures can be mechanical, chemical, biological, or operational in nature. Since each of these measures has its advantages and disadvantages, careful consideration should be made in choosing one or more of them.

Limnologic Monitoring

The results of this investigation have not indicated a definite need for any new practices in the previously discussed areas of operation and management. There is, however, a need for the inauguration of some sort of limnologic monitoring program to depict changes in conditions and to indicate the need to adopt new management practices. The new program should probably include some of the elements of the present study.

Two of the old stations should be included in the new program. The station at the center of the west arm (LA-6) should be maintained since it indicates conditions existing in this shallower portion of the lake. Because of the frequent occurrences of blue-green algae blooms in the Mud Creek arm, the station in the west arm, which is near the old mouth of Mud Creek (LA-MC), should be maintained to indicate any widening of the bloom into that part of the lake. Systematic observations of bottom attached plants should also be made and recorded when in the northerly sector of the west arm.

A new station (LA-H) should be initiated in the easterly part of the lake as a replacement for two old stations, those near the center of the east arm and near the dam. The new station should be between the two old stations and at the deepest point in an east-west cross section about two and one half miles north of the dam. This should result in a total depth greater than that near the center of the east arm, and would be in a less confined area than the deep station near the dam.

A second new station (LA-MI) should also be added near the center of the isolated Mud Creek arm. This station should be located so as to have a depth about half the greatest depth of the arm and still not be overly close to a shoreline.

Nutrient sampling should be conducted at Stations LA-6 and LA-H about ten days after the majority of the ice cover has disappeared. Samples should be collected near the surface, one-third and two-thirds of total depth, and about five feet above the bottom. A vertical temperature profile should be made, and the individual samples should be analysed for dissolved oxygen. The individual samples should be analysed for EC, turbidity, and fluorescence and then composited to be analysed for NO_3^-, NH_4^+, organic nitrogen, filterable and total phosphate, EC, total hardness, alkalinity, turbidity, and phytoplankton volume. Analysis for selected heavy metals could be included, if desired.

A nutrient sample should also be collected from station LA-MI; however, this would probably require a different sampling date since there is usually not much water in Mud Creek arm when the ice dissappears. Mid-May might be the best time to sample LA-MI. If the fluorescence of this sample indicates a moderate or higher phytoplankton volume, special analysis procedure might be needed to detect the total nutrients in the sample. A method to detect total nutrients might include a prolonged storage of the sample in a dark area in order to give the phytoplankton in the sample time to die and decompose; however, this method might require other special techniques for the results to be of value.

In addition to the collection of nutrient samples in spring, other sampling should be conducted on a series of dates about three weeks apart. This work should be carried out from mid-June to mid-August. The stations included in this work should be LA-H, LA-6 and LA-MC, although the work at each would vary.

The first part of this work should be a vertical net-tow at each of the stations conducted as described in Chapter III. Analyses of the collected samples should also be similar to that used in the current investigation.

The second part of the work should start with a vertical temperature profile made by using a depth thermistor. Care should be taken in this work to allow the thermistor to reach true temperature in the thermocline (Birge's) and upper hypolimnion since the temperature data will be used to indicate the occurrence of vertical mixing between sampling dates.

The third part of this work would be the collection of a series of vertical samples. The depth interval for these samples should be one meter at Station LA-H, two meters at LA-6, while two or three samples should be sufficient at LA-MC. Secchi depths should be obtained at all stations. The samples collected should be one for DO, one for fluorescence, and one for phytoplankton. EC sampling could be included if there is evidence of variation in this parameter with depth. Phytoplankton samples should be composited according to results of fluorescence analysis in order to minimize the work. The phytoplankton samples should be analysed for volume and for minimal identification and counts.

In order to maintain a fixed station location at Station LA-H, and perhaps at the other stations, a marker buoy should be installed. The anchor and line on the buoy should be sufficient to hold the boat in position while at the station.

The DO data developed at Station LA-H should be used to determine the depletion rate of DO in the hypolimnion. Special consideration should be given the data to note any mixing between sampling dates.

Sampling should also be conducted at LA-MI to document and define the occurrence of phytoplankton blooms. The timing of this work would need to coincide with the development of such a bloom as determined by periodic observation of this part of the lake.

The adoption of the limnologic monitoring program described above or a similar one is certainly justified by potential value of Lake Almanor; however, it might not be necessary to conduct the work on an annual basis. Two successive years of the full program, followed by two or three years of reduced sampling or no sampling, might be satisfactory.

Fishery Management Program

Historically, Lake Almanor was known for its large rainbow trout. Fish weighing over 10 pounds were commonly caught. However, since the 1940s fishing had declined steadily, and attempts by the Department of Fish and Game to improve fishing by stocking increased numbers of trout have been largely unsuccessful.

The introduction of smallmouth bass (*Micropterus dolomieui*), channel catfish (*Ictalurus punctatus*), Sacramento perch (*Archoplites interruptus*), and kokanee salmon (*Oncorhynchus nerka*) in the 1950s and 1960s provided a greater variety of fish for the fisherman, but catches of these species have remained low. A description of the fishery for the years 1966 through 1972 appears in Appendix D.

The results of the Lake Almanor Limnologic Investigation have shown that nutrient levels and phytoplankton and zooplankton production are sufficient to produce fish populations capable of supporting a significant fishery. Department of Fish and Game studies have shown that much of this production is being channeled into undesirable fish species at the expense of more desirable game fish as is characteristic of many older reservoirs. To rechannel the production into game fish, the Department of Fish and Game has initiated an experimental management program involving: (1) reducing the size of the nongame fish populations by trapping and netting, (2) introduction of a forage

fish, (3) stocking silver salmon (Oncorhynchus kisutch) as a predator fish, and (4) stocking yearling wild rainbow trout raised from eggs taken from the spawning run at Lake Almanor. More detailed descriptions of the programs and other pertinent data appear in Appendix D.

In a lake the size of Almanor, there is little possibility that the total biomass of nongame fish can be reduced by trapping and netting. However, by removing large numbers of adults, the size structure of the populations should shift from primarily large fish that are not utilized as forage to smaller fish that could be utilized by game fish. The introduction and establishment of a small plankton-eating forage fish will fill the gap in the food chain between plankton and fish-eating sport fish and increase growth rates and the numbers of game fish. In addition, they will compete with, and hopefully replace, the undesirable fish but never grow too large to be utilized as the other species now do.